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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-221 *March 1974*

UNDERSTANDING INTERLOCK YARDERS

by

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ABSTRACT

To appreciate the need for interlock devices on a cable logging yarder, one must understand the principle of the interlocking drums on the yarder itself. This paper is designed to promote this understanding and discuss some of the mechanics of good interlock design.

Keywords: Logging, running skylines, cable skidding equipment.

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INTRODUCTION

An "interlock" on a cable logging yarder is not a new device--it dates back to the early steam skidders. Many loggers, recalling the operation of "interlocking the main and haulback drums," may wonder why the interlock has returned as such a popular and much-discussed subject in logging equipment circles. The primary reason is the introduction of a new and popular skyline system, the running skyline, which can benefit greatly from a well-designed interlock device in the system's yarder.

The running skyline (fig. 1) is a versatile cable yarding system well suited to today's logging job. The configuration consists of a haulback (which also serves as a skyline), a main line, and a slackpulling line. A distinguishing feature is the arrangement of the haulback line. With good control of the tensions and line speeds, this arrangement provides slack skyline characteristics for raising and lowering the carriage and the capability for either uphill or downhill yarding. With adequate deflection, all lines in the system provide lift at the carriage. Only a single block needs to be rigged at the tailhold. The main and slackpulling lines provide opportunity to use relatively simple designs for either grapples or tagline feeding type carriages. Although these are characteristics of the cable configuration, they rely heavily on good yarder design which, in the case of a running skyline, is equally dependent upon a well-designed interlock device.

THE NEED FOR INTERLOCKING

The dual function of the haulback line (serving as skyline as well as haulback) provides the increased versatility and lifting capabilities of the running-skyline system; however, it reintroduces the historical interlocking problem into yarder design. This problem has become more critical in running-skyline yarder design because of the system's unique cable configuration and operation.

Proper functioning of the running-skyline system depends upon maintaining the desired tension in the haulback line to control the vertical and horizontal positions of the carriage. Since the haulback terminates on the carriage, the tension in this line creates a resistance against inhauling the system. Therefore, the main power supply must not only meet the requirement for bringing in a turn of logs but also overcome the resistance of the haulback line. This additional power (proportional to the haulback tension times carriage speed) is

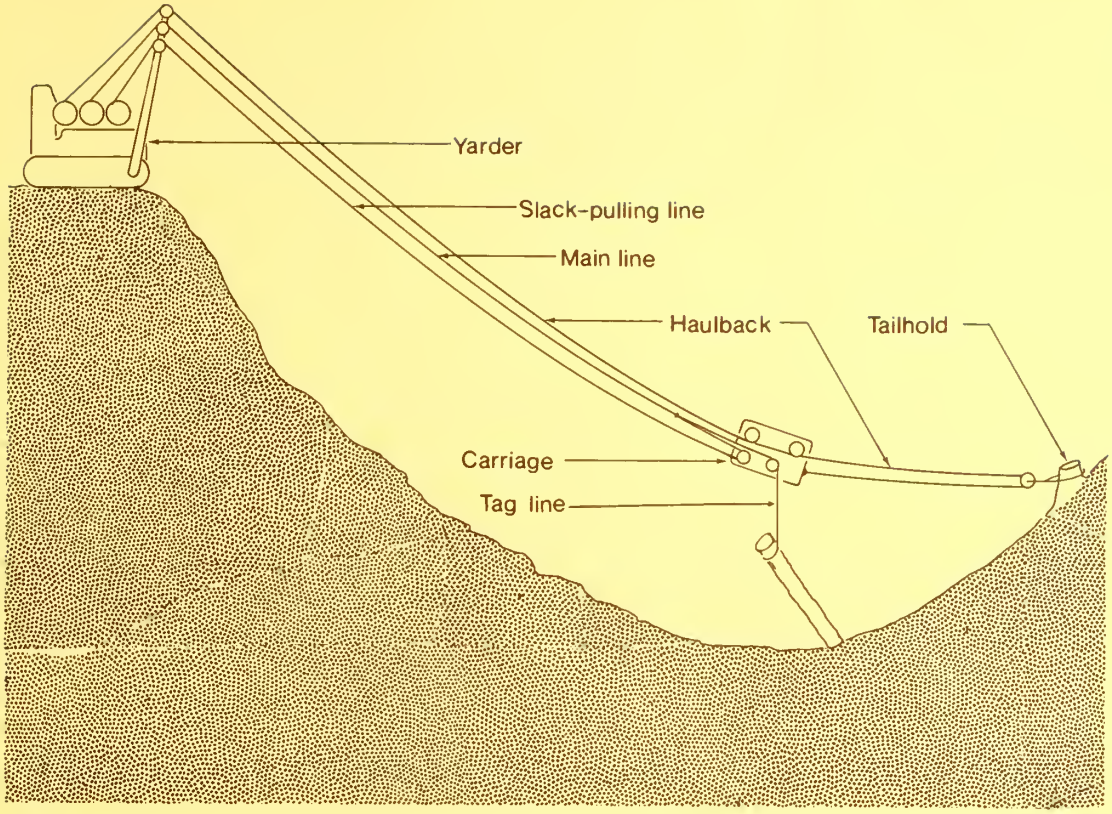

Figure 1.--Running skyline.

not lost directly but shows up in the haulback drum where line is being pulled off under tension. If a retarding brake provides this tension, the power is dissipated in the brake and lost in the form of heat. Depending on line speeds and tensions, several hundred horsepower could be wasted at this point while the operator attempts to keep the haulback taut with the retarding brake. Since this power is supplied at the main drum, it is not hard to conceive of situations where all the power supplied to the main drum is dissipated at the haulback brake and little is left to bring in the log. However, if this power could be conserved at the haulback drum and made available to the main drum drive system, it could reduce the input power required at the main drum. A device to accomplish this, be it hydraulic, mechanical, or electrical, is known as an interlock.

THE INTERLOCK PROBLEM

The "interlock problem," as expressed by the yarder designer, is the need for a device to recover the horsepower potentially wasted at one drum (e.g., in the haulback drum during inhaul) and make it available as a power supply to other drums in the yarder drum set (such as the main line and/or slack-pulling drums). The details of such a device are influenced by the tension, T, and line speed, V. The interlock problem can best be discussed in terms of these variables and how design requirements are related to them.

The power flow to or from a yarder drum can be expressed as the product of the tension on the line and the speed of it, namely,

$$HP \text{ (hp)} = (T, \text{lb}) \ (V, \text{ft/min}) \ / \ (33{,}000 \text{ ft-lb/min/hp}).$$

Figure 2 depicts these variables and shows how they relate to the torque and drum speed through the drum radius; two important points are the direction of power flow and the relationship between power magnitude, torque, line tension, line speed, drum speed, and drum radius. With the algebraic sign convention adopted in figure 2, power flow to the drum, from a power supply such as an engine, would be indicated when cable is wound onto the drum (e.g., the main drum during inhaul). The flow of power is reversed when line is removed from

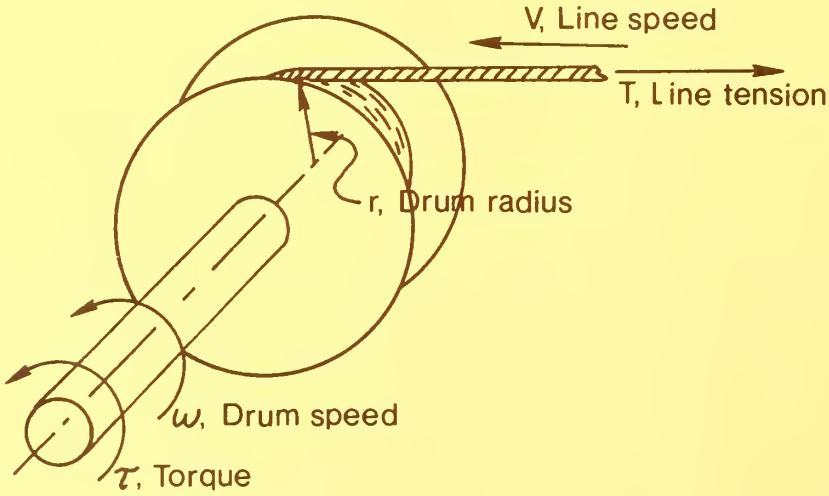

Figure 2.--Yarder drum schematic.

the drum by some external force (such as the carriage pulling line off the haulback drum during inhaul). With line running off the drum, power is flowing into the drum from the cable and must be dissipated in a brake or passed on (through an interlock) and made available to do useful work elsewhere. This concept of power flow into or out of a drum is important to an understanding of the interlock problem.

To examine the interlock problem further, consider the hypothetical running-skyline systems depicted in figures 3 and 4--one without and the other with interlocking capability. Consider the power requirements of the noninterlocking design (fig. 3). During inhaul, with the system tensioned to provide lift, the engine will provide power to the main drum to bring in the load of logs and overcome the resistance of the haulback against the carriage. The power overcoming the usually larger haulback tension enters the haulback drum and is dissipated in the brake being used to retard the drum and develop the tension. As an example of the power dissipated in this brake, a haulback tension of 20,000 lb and a line speed of 1,000 ft/min would cause a loss of over 600 hp at this point. This sacrifice is necessary to maintain this tension and line speed with a brake on the haulback drum.

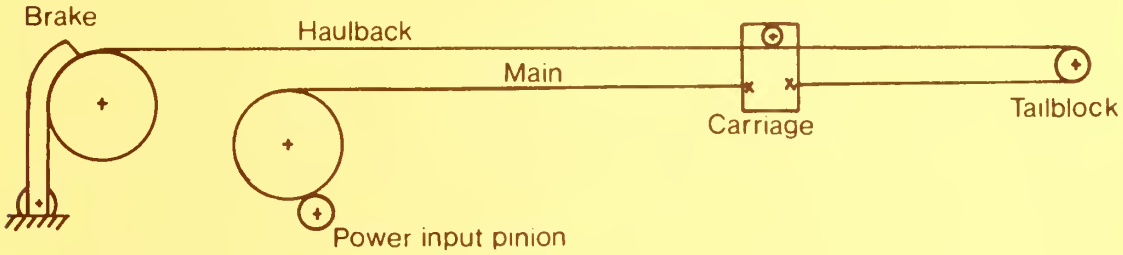

Figure 3.--Running skyline system without interlock.

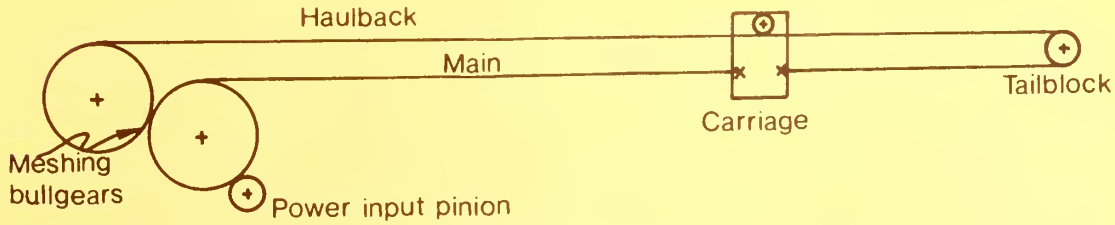

Figure 4.--Running skyline system with interlock.

Now consider the design of figure 4 in which interlocking the haulback and main drums has been accomplished by simply meshing the bullgears of the two drums--the engine still supplies the power to bring in the load of logs; however, the power necessary to overcome the haulback tension is recovered in the haulback drum and made available to the main drum through the meshing bullgears. This results in a direct saving of 600 horsepower. The advantages of efficient interlocking should be readily apparent in this simple example. Unfortunately, practical restrictions make this configuration unworkable as will be discussed in the next section.

THE INTERLOCK DEVICE

At this point it almost seemed that the designer had his solution to the interlock problem with the configuration presented in figure 4. However, further consideration will show this arrangement to be inadequate and will serve to point out the operating details that complicate the interlocking device.

The interlock arrangement presented in figure 4 has the characteristic that while the bullgears are meshed, the angular speed, ω, of the main drum and haulback drum are directly proportional, namely

$$\omega_{main} = n \quad \omega_{haulback}$$

where n is the gear ratio between the two bullgears. If the gear ratio is one to one, the drums will rotate at the same speed but in opposite directions. Such an arrangement would allow line to spool onto the main drum at the same rate it is leaving the haulback *as long as the drum radii on the two drums remain equal* or at least proportional. This is important. If the drums are rotating at the same speeds but the radii vary, the arrangement shown in figure 4 cannot control the relationship between the main line and haulback line speeds; and control of the carriage location is lost. Therefore, the arrangement of figure 4 will successfully transfer the horsepower; however, it has no capability to independently control line speeds.

The requirement for an interlock device to not only transfer power but also provide for control of the relative main and haulback line speeds is important. To understand the interlock problem or the features of any interlock device, one must recognize this problem of line speed control. To emphasize the problem further, consider the drum radius ratio $r_{main} / r_{haulback}$. Unless there is only one wrap on each drum, this ratio will change as the position of the carriage changes and cable builds up on one drum while being removed from the other. If n is constant, as it would be with the meshing bullgears of figure 4, the ratio of the line speeds will go up and down in proportion to the radius ratio (fig. 5). For example, consider the line speeds that would be experienced with a yarder design where

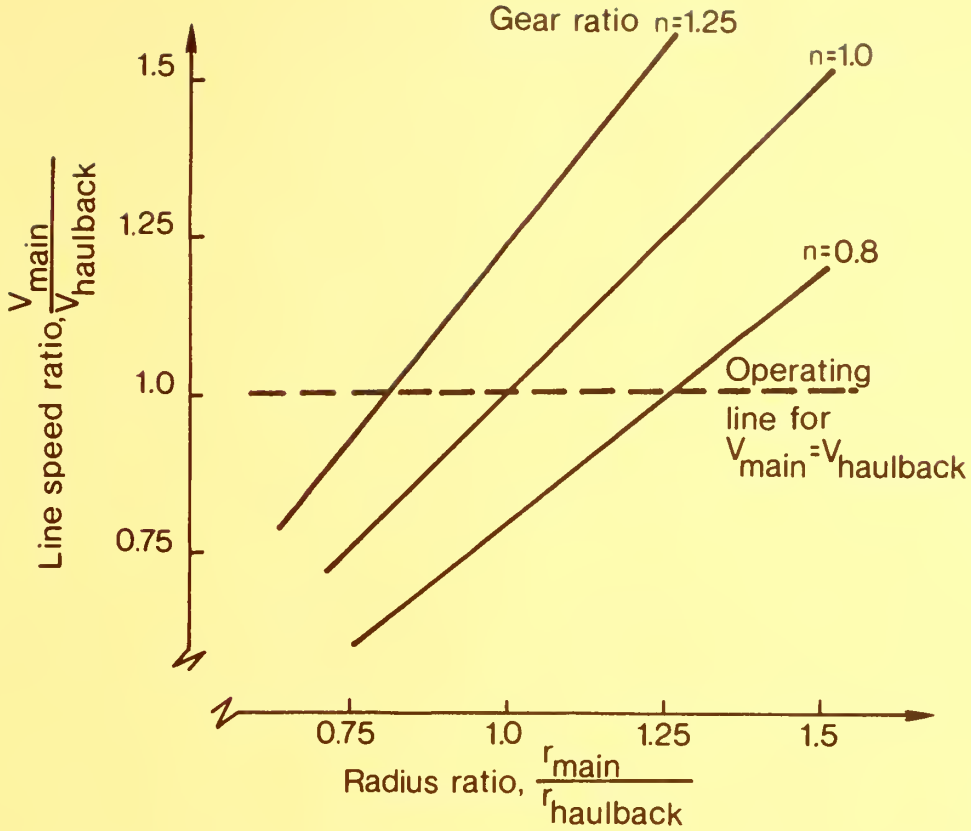

Figure 5.--Line speed-radius and gear ratio relationship.

n = 1.0 and the radius ratio varies from

$$\frac{r_{main}}{r_{haulback}} = 0.8, \text{ carriage at tailhold}$$

to

$$\frac{r_{main}}{r_{haulback}} = 1.25, \text{ carriage at landing.}$$

For a steady main line speed of 1,000 ft/min, figure 5 shows that 1,250 ft/min of haulback is leaving the drum when the carriage is near the tailhold, causing the system to sag; but when the carriage nears the landing, the haulback line will travel too slowly, 800 ft/min, causing the cable system to tighten. In other words, there is no control of carriage position or system tension with the configuration of figure 4. This may be acceptable in special cases; however, in general, this arrangement will be unsatisfactory.

Consider the most likely, desired operating condition of main line speed approximately equal to the haulback speed at all carriage locations. This condition is represented in figure 5 by the dotted line showing the velocity ratio equal to 1.0 for the full range of radius ratios. If this condition is to be maintained, the gear ratio must vary (from $n = 1.25$ to $n = 0.8$ for the previous example) as the radius ratio changes with the carriage traveling from tailhold to landing. Figure 6 shows such an arrangement and a device which functionally interlocks the two drums in the same way the meshing bullgears did but in addition can vary the gear ratio, n, between them. The box contains, by definition, an interlock device. Its function may be accomplished electrically, hydraulically, mechanically, or by some combination of these systems. The system may require power or dissipate power or do both while performing the interlocking task. Whatever the design, the function will be the same, namely, to transfer power from one drum to another in a usable and controllable form.

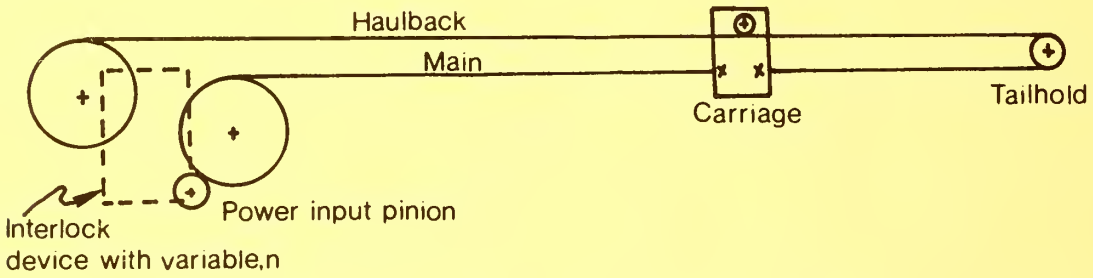

Figure 6.--Running skyline system with variable gear ratio interlock.

CLASSIFICATION OF INTERLOCK DEVICES

For this discussion, interlock devices will be classified into three categories:

1. slipping clutch,
2. planetary interlock,
3. direct drive interlock.

It should be emphasized that this classification is made only for the convenience of discussing the interlock devices that exist or have been proposed. It would be presumptuous to consider these categories to be all inclusive, since many new and innovative interlock devices are almost certain to be developed. As the needs and benefits of interlocking become more clear, creative thinking in this area of yarder design will surely be stimulated.

In discussing the essential features that distinguish these categories of interlocking devices, the schematic representation shown in figure 7 is convenient. This figure depicts the flow of power in the yarder system to the main drum, HP_M, from the haulback drum, HP_H, and power supply, HP_S, and also how they are related through the interlock device. The discussion is limited to the inhaul operation to avoid potentially confusing details and to simplify the schematics, particularly in the slipping clutch arrangement. The power, HP_I, is meant to represent the power supplied (or lost) directly to (or from) the device for the interlocking task. The use of this power will become more clear as individual categories are discussed.

SLIPPING CLUTCH

Figure 8, displayed in the same format as figure 7, expresses the important details of the slipping-clutch interlock. Conceptually, this interlock device is the simplest and therefore the easiest to comprehend.

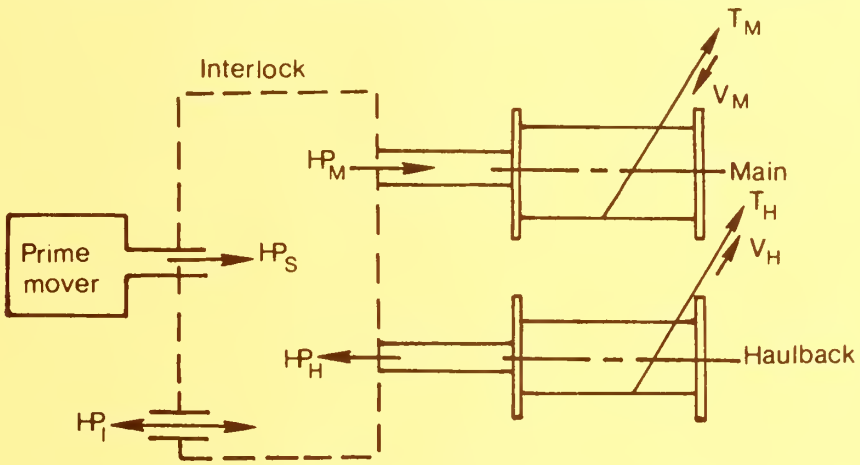

Figure 7.--Schematic of interlock yarder.

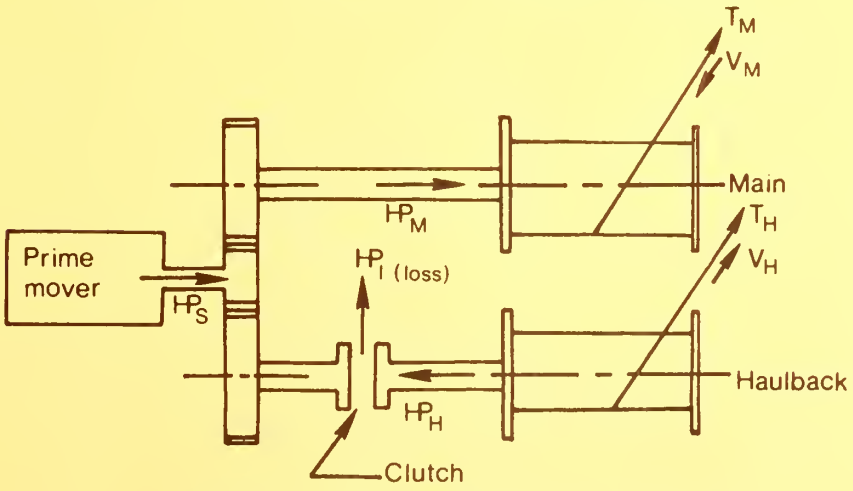

Figure 8.--Slipping clutch interlock.

As an aid to understanding the operating principle of this type of interlock, recall the function of the meshing-bullgear interlock proposed earlier. The objectionable feature of that device was that if the main and haulback line speeds were equal at the tailhold during inhaul, the haulback drum would be going slower than the main drum and thus a gear ratio of $n > 1$ would be required to keep the bullgears meshed. Yet at the landing, relative drum speeds would require $n < 1$. Therefore without a mechanism to vary n, the configuration is unworkable. The mechanism presented in figure 8 deals with this problem by using gear ratios so designed that the right-hand plate of the slipping clutch is always going as fast or faster than the left-hand plate. With this arrangement, the left-hand plate can always be driven at the necessary speed by the right-hand plate and power can be transmitted in the process. Of course, power is always being dissipated at the slipping surface of the clutch except when the two clutch plates are rotating at the same speed (the "lock point"). This power loss, HP_l, is proportional to the product of torque on the clutch face and the difference in speed of the two plates. A typical plot of power loss versus carriage position for this type of device is shown in figure 9. The magnitude of this power loss would depend upon the design variables affecting torque and drum speeds, namely tension, line speed, and the radii developed as the cable packs onto the drums.

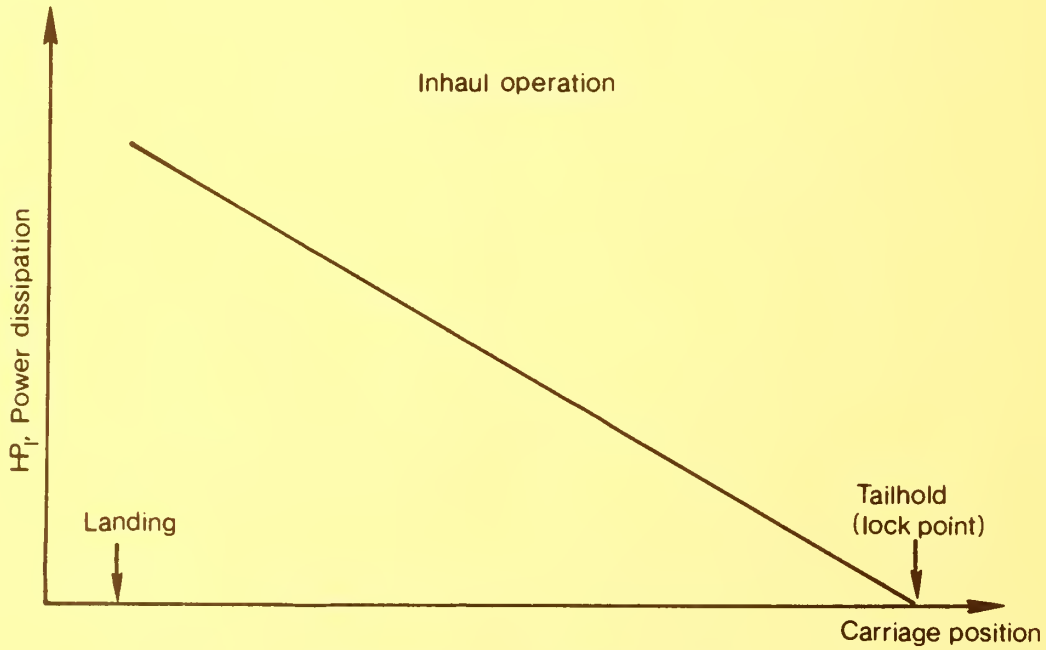

Figure 9.--Power loss in slipping clutch interlock.

PLANETARY INTERLOCK

This category of interlocks, shown in figure 10, employs an arrangement of gears known as planetary or epicyclic gearing. The mechanical details relating the torques and speeds of such an arrangement can appear confusing; however, the functional features are easily understood. The planetary gear train can be used to control the relative speeds of an input shaft and an output shaft by regulating the speed of a third shaft. As an interlock mechanism, it can control the relative speeds of ω_h and ω_h^* by regulating the third shaft, ω_l. This clearly meets the general requirement of an interlock device and accounts for the use of planetaries in many of the interlock yarders being manufactured today.

The planetary does not eliminate the requirement for the power supply (or loss), HP_l. Since speed and torque are required on this third shaft, there must be a means of supplying or removing power at this point. The designer can accommodate this power requirement with a hydraulic or electric motor or dissipate the power in brakes depending upon the overall design. One way to provide HP_l is through a hydrostatic transmission where, by proper design, the overall configuration will operate with no power loss except through the inefficiencies of the transmission itself. Interlock yarders of this design are presently operating in the logging industry.

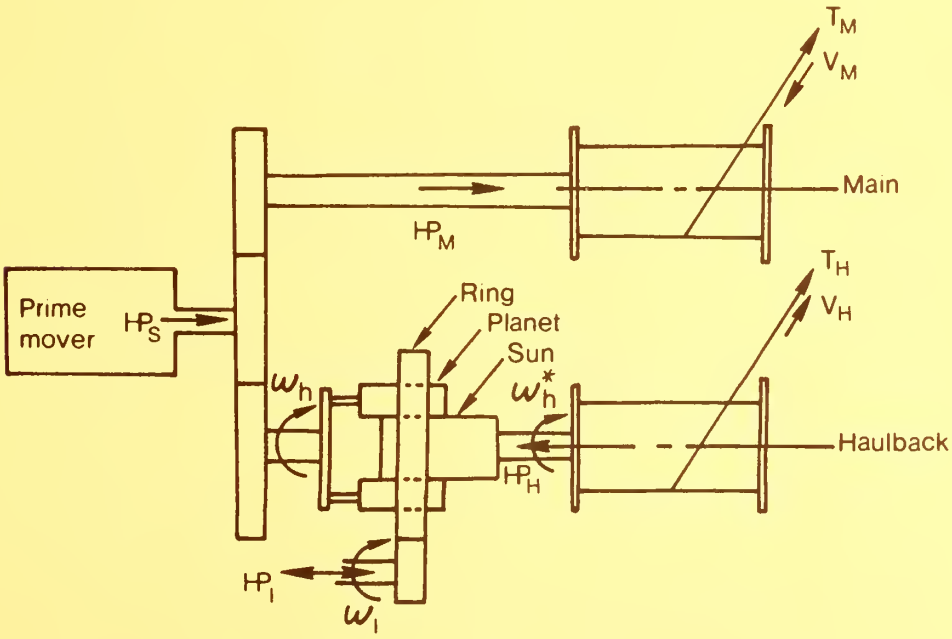

Figure 10.--Planetary gear interlock.

DIRECT DRIVE INTERLOCK

The third category of interlock devices is shown in figure 11. A discussion of this direct drive concept illustrates the principles of interlocking. The concept of this type of interlock can be simply explained if the components are taken as hydraulic pumps and motors as found in a hydrostatic transmission. For example, directly connected to the haulback drum would be a hydraulic pump capable of receiving all the power flowing from this drum during the inhaul operation shown. The pump would have variable displacement capability, controlled externally by a swashplate angle, θ, so that power flow to or from this pump could be regulated regardless of the speed of the drive shaft coming from the haulback drum. During inhaul, the main drum would be driven by the prime mover and the hydraulic motor. In this configuration, the prime mover would supply the power to yard the logs and overcome losses at other points in the system. In such a system, the haulback cable tension is proportional to the pressure in the hydraulic unit, and the relative drum speeds are proportional to the fluid flow controlled by the pump displacement. Of course, controls for such a device can become complicated; however, conceptually it should be clear how this arrangement provides a straightforward solution to the interlocking problem.

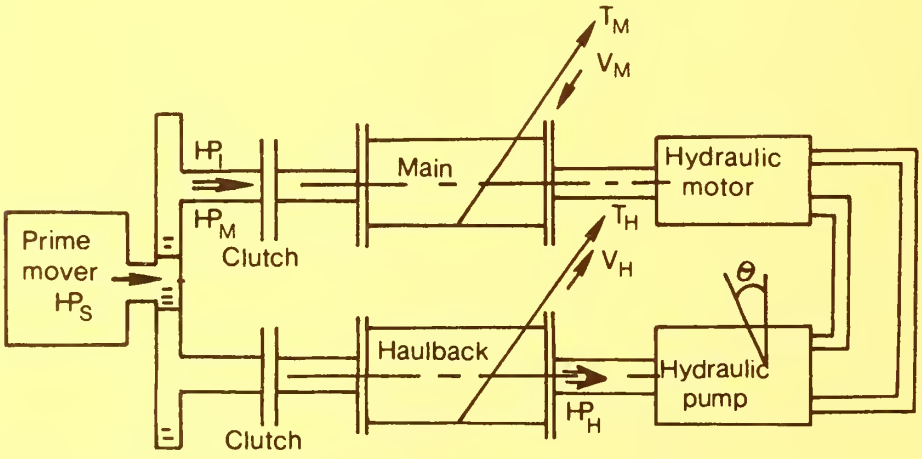

Figure 11.--Direct drive hydraulic interlock.

CONCLUSIONS

The need for and advantages of interlocking the main and haulback drums of a running-skyline yarder to conserve power are apparent. The conceptual details of three fundamental interlock devices were examined to illustrate how interlocking can be accomplished. A final design would use one or a combination of these arrangements for conserving power.

Beyond this ability to conserve power, an important feature of any such device is its controllability. The regulation of tensions and line speeds for positioning the carriage is a direct function of the interlock control. Control characteristics are of major importance when distinguishing the advantages and disadvantages of an interlock design.

In conclusion, we hope this paper has promoted an understanding of and an appreciation for the interlock problem. It should be clear that the scope of this paper was limited to a description of the problem and the basic conceptual features of interlocking device designs. Further discussion of the problem and design alternatives perhaps would be enhanced by mathematical analysis, which was purposely avoided in this paper. However, a sequel is planned in which the details of the interlock problem will be discussed more thoroughly. Such a paper will be directed more to the control features and the quantitative aspects of an interlocking device.

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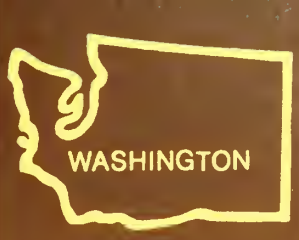

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-222 *March 1974*

A SUGGESTED METHOD FOR COMPARING CONTAINERIZED AND BARE-ROOT SEEDLING PERFORMANCE ON FOREST LANDS

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and

William I. Stein, *Principal Plant Ecologist*

ABSTRACT

Procedures are proposed for making uniform field comparisons of containerized and bare-root nursery stock. If such comparisons are made in many areas, enough data can be cooperatively accumulated from which to develop sound guidelines for use of containerized seedlings.

Keywords: Nursery stock, outplanting, research.

EST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Containerized seedlings are being produced and outplanted by the millions on forest lands in the Pacific Northwest. Approximately 23 million were grown in Oregon and Washington greenhouses and nurseries in 1973, and it appears 1974 production will increase by at least 10 million.[1/] Most containerized stock is grown from seed in plastic or styrofoam containers holding various mixtures of peat moss, vermiculite, tree bark, perlite, and sand. Before outplanting, seedlings are extracted from their containers and their compact roots hold together a semirigid plug of potting mix.

Rapid expansion of container reforestation systems in the past several years is undoubtedly due to their managerial and operational advantages: Production can be expanded rapidly with less capital investment in land and equipment than is needed for bare-root nurseries; less leadtime is necessary between reforestation planning and planting; roots are less exposed; and seedlings can be planted more quickly during longer seasons than for bare-root stock. But how are the huge numbers of "good looking" containerized seedlings performing after outplanting?

FIELD PERFORMANCE TRIALS NEEDED

Published results on field performance in Oregon and Washington are few and preliminary.[2/] Furthermore, available test results are for containerized seedlings produced in earlier stages of the rapidly evolving production technology. This technology has far outdistanced systematic field testing, and concerted effort is urgently needed to adequately evaluate seedling performance. Answers are needed to such questions as: (1) What is the comparative survival and growth

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[1/] Frank A. Ter Bush. Seedling production and capacity. USDA Forest Service Pacific Northwest Region, Forestation Notes No. 20: 1-4. 1973.

[2/] James Dick. Container planting in Oregon and Washington. *In*: Western Reforestation. Western Forestry and Conservation Association Western Reforestation Coordinating Committee Proceedings 1969: 41-44. 1970.

Peyton W. Owston. Field performance of containerized seedlings in the Western United States. Western Forestry and Conservation Association Permanent Association Committees Proceedings 1972: 109-112. 1973.

Peyton W. Owston and William I. Stein. First-year performance of Douglas-fir and noble fir outplanted in large containers. USDA Forest Service Research Note PNW-174, 10 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1972.

of containerized and bare-root stock? (2) In which situations do containerized trees outstrip, or fall short of, bare-root stock performance? (3) What are the comparative reforestation costs using bare-root or containerized trees? Much information on field performance and cost must be collected before a comprehensive evaluation of containerized reforestation is possible.

Simple methods for making critical survival and growth comparisons between containerized and bare-root stock are described in the pages that follow.[3/] These methods are used in widespread field trials now being installed in a 5-year pilot program on National Forests in Oregon and Washington. We encourage others to use the same methods. By using the same design and procedures in many localities, enough data will be accumulated from which to develop sound guidelines on use of containerized seedlings on individual ownerships and for regional areas.

Members of the Pacific Northwest Forest and Range Experiment Station seek to cooperate with organizations or individuals interested in evaluating containerized seedling performance. Common use of the sample forms will permit ready pooling of data and standardized analyses. Please contact us to work out cooperative endeavors on a timely basis.

PROCEDURES FOR COMPARING CONTAINERIZED AND BARE-ROOT SEEDLINGS

The installation described below is a reasonable minimum for comparing in one locality a single type of containerized seedling with a single type of bare-root stock of the same species. The basic objective of such a comparison is to answer the question:

> Under the given site conditions, do (species) seedlings grown from seed in (type) containers survive and grow better after outplanting than (size or age class) bare-root stock?

Inferences about different production techniques, species, stock types, and sites may be drawn from results produced by a large number of these individual experiments.

[3/] More intensive and involved tests than those described may sometimes be desirable or needed. Consultation with a statistician is highly recommended before launching any complex study.

PLOT ESTABLISHMENT

Locate four plots (replications) within the locality of interest. All plots may be in one reforestation unit or one plot may be placed in each of four units. The site--soil type, slope, aspect, ground cover, etc.--should be as uniform as possible within each plot, but conditions among plots of a set may be varied or uniform depending upon the information desired; e.g., all four may be on south aspects if that is the main area of interest, or aspect may be varied so that inferences about container planting can be made for the locality in general. Other site factors can be handled similarly. Plot locations should be recorded on a map of the reforestation unit(s). Nearby stumps, logs, and brush can be indicated on sketches of individual plots, if this appears desirable.

Each of the four plots should contain four rows of 25 planting spots each--400 trees for planting at one time in each set of four plots. Comparison of fall and spring planting would require doubling of rows per plot and appropriate random assignment of an equal number of rows for planting in each season. Rows should be oriented up-and-down slope and numbered in order, 1 to 4, or 1 to 8. A field spacing of 6 feet between rows and 6 feet between planting spots is suggested as reasonable for minimum site variation within plots and convenience of remeasurement. Even closer spacings may be used if sufficient good planting spots are available and reduced plot size seems desirable.

The kind of tree to be planted in each row within a plot should be designated at random. An easy way to accomplish such randomization is to drop four folded slips into a hat or box, two bearing the word "bare-root" and two "container." Row 1 receives the stock listed on the first slip drawn sight unseen after shaking the hat, row 2 the next, and so on. When a fall vs. spring planting comparison is included, eight rows are involved and eight slips are used, two each labeled bare-root fall, bare-root spring, container-fall, and container-spring. Random assignment of stock to rows should be made independently for each plot of a set.

To help prevent bias and to obtain well-arranged plots for convenient reexamination, it is advisable to use guide ropes during planting or to stake planting spots in advance with flagged 20-inch wire pins; e.g., red for containerized stock, blue for bare-root stock. Rows should be kept reasonably straight; unplantable spots should be skipped and each row extended far enough to provide

25 plantable spots. Ends of each row should be marked with wooden stakes, except the one for the outside row in each plot ending nearest the access road which should be a tall steel or wooden post. Plots should be signed adequately and rows labelled clearly.

The items and quantity needed for installing a single set of four plots planted in one season are listed below. The 50 extra trees of each kind are to be used for size determination and for those isolated instances when field culling seems prudent.

Item	Number needed
Containerized trees	250
Bare-root trees	250
Steel or wooden posts	4
Wooden stakes (about 3 feet long)	28
Flagged wire pins, red	200
Flagged wire pins, blue	200
Planting tools	Various
Data sheets	Various
Area map	1

PLANTING AND TENDING

Several stock and planting requirements must be met to insure an unbiased comparison of containerized and bare-root trees:

1. Containerized and bare-root stock should be of the same seed source, and both lots should appear healthy and sturdy. Each type of stock should be representative, with extremely large or small seedlings removed to attain a reasonably homogenous sample. They should both be given good and comparable preplanting care--i.e., handling, storage, and transporting should be minimized, and done so that the trees do not become dry, overheated, or physically damaged.

2. Plant only when air temperature is above freezing during actual hours of work, soil is moist and unfrozen, and any snow cover is less than 2 inches deep. Both types of stock should be planted concurrently to minimize unequal effects caused by changing weather, i.e., don't plant one type in the morning and the other in the afternoon.

3. Good planting technique and comparable effort must be used for both types of stock--i.e., vegetation and debris should be removed uniformly from all spots, trees should be planted with roots straight down in mineral soil to a depth between the root collar and the first green foliage, and the soil should be packed tightly enough to prevent air pockets, easy pulling by animals, or frost heaving. No attempt should be made to achieve normal production rates in test plantings.

4. Trees should be planted in the most favorable place within a 2-foot radius of the marked spots. If no plantable ground is found in the designated circle, move on to the next designated spot. Immediately after planting, the wire pin marking each spot should be placed north of and within 4 inches of the tree. Pins should be left in place throughout the study and may be numbered to facilitate tree reexaminations.

5. Ideally, one person should plant the 100 trees in one plot to eliminate planter variation. If this is not done, an honest effort must be made to have individuals plant an equal number of each type of stock. Under no circumstances should one person plant all container seedlings and another person all bare-root stock.

In essence, the person in charge should make every effort to insure that handling and planting procedures do not favor one type of stock over the other.

If one type of stock is treated with animal repellent before or after planting, the other type should also be treated. Other postplanting protection from animals should be provided at the discretion of the forester in charge. Again, both containerized and bare-root trees should be treated similarly; e.g., if not all trees are protected, half of each kind might be caged to prevent browsing.

Wildings of the species being tested should be removed from the plots if their presence might cause confusion initially or during reexaminations.

DATA COLLECTION AND ANALYSIS

A planting report (Form 1) should be completed by the person in charge as soon as a set of plots has been planted. This report provides key information on stock characteristics, site description, and planting conditions. It is also highly desirable to determine initial top length, stem diameter, and dry weight of both containerized and bare-root trees (Form 2). These data are obtained by measuring, drying, and weighing a representative sample of 25 bare-root and 25 containerized trees drawn at random before both lots are planted. Measurement of the sample trees is best done indoors at a workbench; determining ovendry weight will require washing facilities, a drying oven, and a balance. Data obtained from sample trees will characterize the stock used and will aid in interpreting results.

Survival of planted trees should be checked in the first spring after fall planting, and after the first, third, and fifth growing season for both fall and spring plantings (Form 3). A cumulative record should be obtained, which requires keeping track of each tree individually by position in plot and row. An undamaged tree should be considered alive as long as it bears any green foliage; death of a clipped or broken tree is not certain if live cambium is still present on the stub.

Total height of seedlings should be measured at intervals (Form 3). Initial height is useful for later determination of growth. It can be measured immediately after planting or can be determined for most species at the end of the first growing season by measuring from ground line to the point of last bud break. Measurement of total height or of height growth each fall that survival is checked is desirable; but it this is not possible, total height should at least be measured at the end of the third and fifth growing seasons.

Heights, stem diameters, and dry weights of conifer seedlings are determined in a variety of ways. For the sake of uniformity, the procedures listed, which are based primarily on a committee report of the Society of American Foresters,[4/] are recommended:

[4/] Society of American Foresters. Report of the ad hoc committee on nursery stock measurement procedures. Journal of Forestry 67: 52-53. 1969.

Top length

Measure to the nearest centimeter from the base of the terminal bud to the root collar, defined as a point on the stem 2.5 centimeters below the cotyledonary scar.

Stem diameter

Measure to the nearest 0.5 millimeter at a point 2.5 centimeters below the cotyledonary scar.

Total height

Measure to the nearest centimeter from average ground level to the base of the terminal bud, if present, or to the highest live point of the central stem if the terminal bud is missing.

Ovendry weight

Dry trees 48 hours at 70°C or until no further weight losses occur. Weigh the bulk sample to the nearest 0.1 gram.

Careful size and weight determinations are, of course, desirable, but extreme exactness is not needed to adequately establish average seedling size and dry weight.

Established photo points, from which to take pictures at every remeasurement, provide a highly informative adjunct to any study installation.

Survival and height growth data from a set of four plots may be analyzed statistically according to the following analysis of variance table:

Source of variation	Degrees of freedom
Plots (replications)	3
Stock types	1
Error	3
Subsampling	8
Total	15

If fall and spring planting comparisons are made in a particular set of plots, the analysis of variance table would be as follows:

Source of variation	Degrees of freedom
Plots (replications)	3
Seasons	1
Stock types	1
Interactions	1
Error	9
Subsampling	16
Total	31

When survival differs markedly between container and bare-root stock, statistical adjustments for unequal numbers may be necessary in later growth comparisons.

Form 1

PLANTING REPORT

Organization and admin. unit _____ Study no._____

Study location: T __ __, R __ __, S _____, _____

Stock characteristics	Containerized seedlings	Bare-root stock
Species & lot ident.		
Seed zone & elev.		
Stock age & root lgth.		
Container name & size		
Nursery name & facilities used (greenhouse, shadehouse, combination, etc.)		
Date lifted		
Date shipped		
Packaging (in containers, bags, boxes, etc.)		
Protective treatment(s)		
Type and duration of storage at work center		

Site description: Elev. (ft)_____ Slope (%)_____ Aspect_____

Unit size (ac)_____ Soil surface texture_____

Significant features (heavy competition, animal presence, shallow soil, etc.)_____

_____

_____

Planting conditions: Date(s)_____ Weather (temp., wind, cloud cover, prec.

_____

Soil moisture_____ Cohesiveness of containerized seedling root balls (plugs)_____

Tools used -- Containerized_____ Bare-root_____

Protective treatment applied_____

Planters initials: Plot 1_____, 2_____, 3_____, 4_____

Additional comments: (logging or fire history, site prep., previous reforest. attempts, comments on stock and planting conditions -- were seedling roots dry, planters new or experienced, tools satisfactory, etc.)._____

_____

_____

_____

rm 2

DESCRIPTION OF STOCK PLANTED

ganization and admin. unit_____ Study no._____

udy location: T __ __, R __ __, S _____, _____

ecies_____ Sampled and measured by_____ Date_____

ree o.	Containerized seedlings Ident. and general descript.:		Bare-root stock Ident. and general descript.:		
	Top lgth. (cm)	Stem diam. (mm)	Top lgth. (cm)	Stem diam. (mm)	Root lgth. (cm)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
otal					
ver.					

Oven-dry weight (grams)

	Tops	Roots	Tops	Roots
Total				
Aver. wt./plant				

Form 3

SURVIVAL AND GROWTH RECORD

Organization and admin. unit _____ Study no. _____

Study location: T __ __, R __ __, S _____, _____

Plot no. _____ Row. no. _____ Date planted _____ Species _____ Stock type _____

Dir. row traveled _____ Recorder _____, _____, _____, _____

Tree no.	Date:			Date:			Date:			Date:		
	Surv.	Ht. (cm)	Cond.	Surv.	Ht. (cm)	Cond.	Surv.	Ht. (cm)	Cond.	Surv.	Ht. (cm)	Cond
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
Total												
Aver.												

CODING: Survival - 1 = live seedling
0 = dead seedling
M = missing

Condition - A = animal damage
FH = frost heaved
B = buried

NOTES: Use a separate form for each row to provide space for recording data from successive examinations. Record cause of mortality when known.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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An Introduction to CODINVOLVE: A System for Analyzing, Storing, and Retrieving Public Input to Resource Decisions

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SCI., TECH. & AGR. DIV.

by

Roger N. Clark
George H. Stankey
John C. Hendee[1/]

ABSTRACT

The Codinvolve System for analyzing the content of public input was developed in response to increasing requests by land managers for a tool to handle the citizen input they were receiving. The concepts and criteria on which the system was based are discussed. General procedures for applying Codinvolve are explained.

Keywords: Information retrieval systems, public opinion, public policy (- forests.

[1/] The authors are research social scientist, Pacific Northwest Forest and Range Experiment Station, Seattle; research social scientist, Intermountain Forest and Range Experiment Station, Missoula; and recreation-research project leader, Pacific Northwest Forest and Range Experiment Station, Seattle.

REST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

The purpose of this research note is to describe the Codinvolve System in general terms and show how it can be used to analyze public input and where it fits in the public involvement process. It explains the basic concepts and assumptions underlying Codinvolve. But this is not a comprehensive instructional guide. Readers interested in applying the system are referred to the users' manual.[2/]

THE NEED FOR A WAY TO ANALYZE PUBLIC INPUT

Public involvement in decisionmaking has become a way of life for resource managers. Laws, agency policies, and sincere desire to do a better job of management have led to programs soliciting public input. Citizen response often has been overwhelming. Administrators swamped with literally thousands of inputs of varying kinds and complexity are asking, "What now?"

The Codinvolve System was developed to handle these accumulations in a systematic, objective fashion. The important opinions, values, and factual and emotional information need not be obscured by sheer volume. The whole spectrum of public input now can be summarized for decisionmakers to review easily.

The basic concept underlying systematic content analysis of public input is that the common denominators of virtually all public input are the opinions offered for, against, or about the issues in question. These opinions are frequently supported by reasons. The number and kinds of reasons can vary considerably, even those given to support the same opinion.

This combination of opinions and their supporting reasons defines the values the public holds with regard to the issue in question. Opinions offered with incorrect or inaccurate reasoning might sometimes be subject to change with new information--but they still tell something about the value orientations of the public and give valuable clues about how the agency might respond.

The basic goal of systematic analysis of public input is to identify and display in detail the combination of opinions and supporting reasons contained in the public input received by decisionmakers.

[2/] Photocopies of the Codinvolve Users' Manual by Roger N. Clark, George H. Stankey, and John C. Hendee will be available after June 1974 from Recreation Research, 4507 University Way N.E., Seattle, Washington 98105.

CODINVOLVE: WHAT IT IS AND IS NOT

Codinvolve is a flexible, content-analysis system specifically designed for objective analysis of public input--coding, storing, retrieving, summarizing, and displaying that input as it is needed. Codinvolve is based on a coding process which provides quantitative summaries of all opinions expressed (how many opinions for or against an alternative or issue) and qualitative descriptions of supporting reasons (why people feel as they do). Regardless of the form which input takes (personal letter, petition, report, or whatever), Codinvolve readily breaks down the content by opinion expressed and reasons given to support it. A major advantage of the system is that it stores all the information contained in the input for future retrieval, a valuable aid to multiple-use planning or special area management over several years' time.

Codinvolve *is not* a computer program or an edge-punch, card-sorting system. Codinvolve is a "systems" approach for analyzing public input; computers and edge-punch, card-sorting procedures are two tools used to do the job. The choice of which tool to use depends on the amount of input and the complexity of the particular issue.

Codinvolve is a "systems" approach for analyzing public input; computers and edge-punch card sorting are two tools used to get the job done.

THE CODINVOLVE SYSTEM'S BACKGROUND

Codinvolve was developed in response to a growing number of requests from Forest Service resource managers for assistance in handling large amounts of public input. These managers were concerned that without a systematic way of analyzing and summarizing the input, they were being swamped by its volume. How then could they follow through on their pledge to the public to consider all opinions.

An early effort to apply content analysis was made in 1969 on the Wilderness Study of the Mission Mountain Primitive Area in Montana (Stankey 1972). There, content analysis was applied to public input, but without a comprehensive "systems" approach to coding, analyzing, displaying, storing, and retrieving the data.

The Codinvolve System was developed and tested early in 1972 when large amounts of public input poured in to the Forest Service in response to its roadless-area review and some controversial environmental-impact statements. Since then, Codinvolve has been field tested, revised, and improved. It has been applied to more than 20 different National Forest management issues involving more than 30,000 pieces of public input. It has been used on such specific topics as proposing new areas for wilderness classification and on broad, multiple-use planning tasks involving numerous interrelated issues. On every issue to which it was applied, Codinvolve won endorsement for providing a useful summary and analysis of voluminous public input.

In September 1973, a Forest Service research-applications workshop on public input analysis was held in Seattle, Washington. In it, a cadre of 35 people from the Forest Service across the Nation learned to use Codinvolve in analyzing public input. These people now are applying the Codinvolve System to management issues in their home regions and holding training sessions to further extend the technique.

Several other Federal and State agencies are also involved in applying the system to their needs.

CODINVOLVE AND THE PUBLIC INVOLVEMENT PROCESS

Public-involvement programs come in many forms and include many activities depending on the planners' approach and the complexity of the issues involved (Frear 1973, Hendee et al. 1973, Reinke and Reinke 1973). Regardless of the overall approach used, if public response is large, an analysis system such as Codinvolve will be needed.

The Codinvolve System is used after input has been received. Users of the system must take public expressions at face value since Codinvolve won't make corrections for any shortcomings in citizens' input. Although using the system can provide insight into other

aspects of public involvement, it cannot assure effective public involvement when used alone. Codinvolve will not make judgments, nor will it make decisions. It is a tool for analysis--nothing more.

PRINCIPLES THAT MAKE PUBLIC INPUT ANALYSIS EFFECTIVE[3/]

The purpose of analysis is to summarize and display the number, content, and nature of public responses so that they can be considered in making recommendations and decisions. Thus, public-input analysis seeks to identify public opinion and values, their underlying reasons, and new ideas and information about issues, geographic areas, and resource-management alternatives.

To fully understand the Codinvolve System, it is necessary to examine the principles on which it is based. We feel that any system for analyzing public input should satisfy these criteria:

1. *Analysis is separate from evaluation.* Evaluation is subjective. It interprets the importance of various kinds of public input and integrates them with other factors in order to reach a decision. The importance of various kinds of input is decided in the evaluation stage, *not* during analysis. Analysis seeks only to describe what the public said as completely and directly as possible; it does not assign any weights or policy recommendations. But analysis must describe how the input differed according to variables the decisionmaker might think are important. For example, it might compare the content of letters with that of petitions, show local views in relation to nonlocal ones, or sort out individual responses from those of groups.

2. *Decisionmaking questions guide analysis.* Before analysis can be meaningful, the decisionmaker must spell out questions he wants answered about the public input he has received. Often, full-scale public-involvement efforts are undertaken without any formal consideration of how public input will be analyzed or focused on the issue in question.

Analysis attempts to answer such questions as: What opinions were expressed concerning management alternatives, general issues, and specific areas? Why do people feel as they do, or what reasons were given to support the opinions they expressed? How did opinions vary according to such important factors as form of input (statements at

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[3/] Much of the following material comes from John C. Hendee, Roger N. Clark, and George H. Stankey. 1974. A Framework for Using Public Input in Resource Decision-making. Manuscript awaiting publication in the Journal of Soil and Water Conservation. A 30-minute slide-tape presentation of these concepts also has been developed by the authors and is available from Recreation Research, 4507 University Way N.E., Seattle, Washington 98105.

meetings, personal letters, formal reports, petitions, form letters, etc.)? Who responded (individuals or organizations)? Where did the input originate (locally, regionally, or nationally)? What additional information, ideas, and issues were presented?

If the decisionmaker can spell out early in the public involvement process those questions he needs answered, a much more effective job can be done in obtaining and analyzing input to provide useful information.

3. *All input is relevant and must be processed.* Because all input expresses opinions and values, it all has implications important to the decisionmaker. Analysis must include all input, regardless of its form or detail. Both general opinions and well-reasoned arguments (some of them highly complex proposals) are expressions of values. They differ only in level of understanding and articulateness with regard to technical matters and resource-management detail. Thus, analysis must record and summarize all public input--including emotional statements, general opinions, and other expressions of values--as well as the more specific comments and detailed management proposals.

4. *Analysis must be systematic, objective, visible, and traceable.* Effective analysis calls for these characteristics:

It must be *systematic.* Analysis should follow a structured procedure which checks and balances the way in which input is handled and processed.

It must be *objective.* Personal prejudices and subjectivity must not affect the way in which input is summarized. Analysis must assure that an independent review would generate the same information.

It must be *visible.* It must be recognized by administrators and public alike as a distinct and necessary phase in the public-involvement process. In addition, the product of analysis must be available for review by concerned parties.

It must be *traceable.* An independent party should be able to follow the manner in which input was handled. The system must leave "tracks" so analysis could be replicated.

5. *Identity of the input must be maintained.* It is important that no combining, weighing, or evaluating of input be done during the analysis. Results from different kinds of public involvement must be summarized separately so the decisionmaker can distinguish between different kinds of input when deciding what importance to attach to them. Results of workshops cannot be lumped with personal letters, responses from organizations cannot be combined with individual opinions, and oral statements cannot be included with petitions because there may be different implications for each kind of input.

Their contents must be summarized separately so each can be studied for its unique implications.

6. *Analysis must be a continuing process.* Analyzing citizen input can be a problem because important resource-management decisions often evolve over several years. Public input which affects a given decision might be solicited and concentrated in a critical period prior to the decision. However, many inputs precede or follow the formal collection stage, in some cases by several years. The balance of opinion can change as more people become involved, more and better information is obtained, and public attitudes shift in response to changing situations. For instance, the recent "energy crisis" has probably caused some people to change their attitudes about coal mining. Therefore, it is essential that the analysis of public input reflect comments made before any special appeal for response, and that subsequent input be recorded for subsequent retrieval when needed, or when significant shifts in opinion and values are suspected. Interested persons should not be required to resubmit their views time and again to coincide with administrative convenience. It should be possible for managers to consider all input, even that which does not follow a special appeal for response.

CRITERIA FOR EFFECTIVE ANALYSIS

From these broad principles, we can derive specific criteria for an ideal method of analyzing public input:

a. The method should *summarize the extent, content, and nature of public input* in relation to the decisionmakers' questions.

b. It must be *objective.*

c. It should be *visible* and *traceable.*

d. It must be *reliable* in that the opinions expressed are recorded the same way by different analysts.

e. It should provide for *uniform application between different administrative units.*

f. It should be *flexible to accommodate different conditions.*

g. It should have the *capacity* to handle large quantities of input, have *storage* and *retrieval* capabilities, and capacity to assimilate *continuing* input.

h. It should *summarize the balance of opinions expressed and describe variations in each opinion.*

i. It should *provide other descriptive and qualitative information about the content and nature of the input.*

j. It should *facilitate environmental analysis leading to the preparation of final, environmental-impact statements* by identifying significant new information and arguments for and against the proposed actions.

Although there is no single ideal method for analyzing public input, the system chosen should be examined in light of the above. These criteria have guided development of the Codinvolve System.

STEPS IN COMPLETING A CODINVOLVE ANALYSIS OF PUBLIC INPUT

Codinvolve provides for the orderly and systematic transfer of information contained in any type of written input to a form that can be summarized easily for review. The basic steps in completing a Codinvolve analysis are shown in figure 1. The diagram also distinguishes analysis from evaluation. With input in hand, the analyst must provide an objective summary which answers the decisionmakers' questions and describes the full content of that input. Briefly, steps in doing this job are:

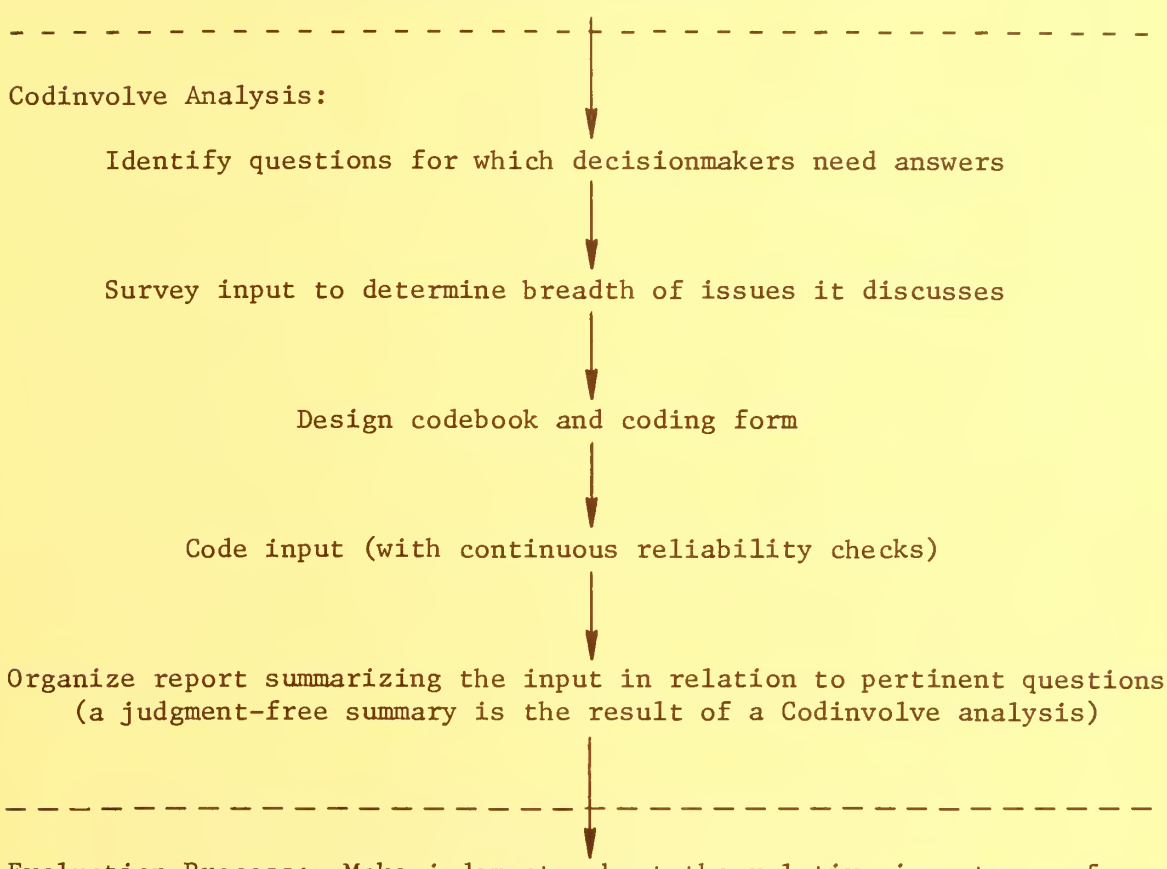
1. *Identifying questions for which decisionmakers need answers.* It is essential that the analyst know what information the decisionmaker wants from the public input. What is he looking for? This is the key to a useful analysis. The analyst must consult decisionmakers to insure that nothing important is overlooked. (See page 5 for examples of specific questions decisionmakers often ask.)

2. *Surveying input to determine breadth of issues it discusses.* This step provides an overview of issues discussed and information provided in the input. Although it is important to specify decisionmaking questions, it is just as important that the structure of the analysis system not filter out any new or unanticipated information. To be responsive to the varying nature of input, the analysis system must have the capability to capture the full breadth of public input so it can be summarized for review.

In order to determine the breadth of issues which input discusses, a sample of input is captured by means of a content summary reflecting the substance of comments. The content summary defines the range and diversity of opinions, supporting reasons, and factual material contained in the input.

3. *Designing codebook and summary form.* The two basic documents for a Codinvolve analysis--the codebook and summary form--are built around the results of the previous step.

Figure 1.--*Flow diagram focusing on a Codinvolve analysis.*


Public input in hand acquired by various processes
(meetings, letters, workshops, etc.)
Codinvolve Analysis:
Identify questions for which decisionmakers need answers
Survey input to determine breadth of issues it discusses
Design codebook and coding form
Code input (with continuous reliability checks)
Organize report summarizing the input in relation to pertinent questions
(a judgment-free summary is the result of a Codinvolve analysis)
Evaluation Process: Make judgments about the relative importance of the various kinds of public input in relation to other decisionmaking factors.

The *codebook* contains instructions, definitions, and examples which show how information should be coded. It is a basic reference document, and any changes in coding procedures must be noted in it. It is important that the codebook contain detailed and clear instructions. Reliability, the assurance that each coder's work will replicate that of other coders, is crucial to the system's success. In order to insure reliability among coders, the set of instructions from which they work must be clearly understandable and uniform.

The codebook tells the coder how to use the *summary form* on which information from the input will be recorded. Depending upon specific circumstances, the summary form might be an edge-punch card (as has been used in several Codinvolve studies) (fig. 2) or a computer card.

4. *Coding input.* Coding is the process of transferring the content of public input to a form that facilitates summary. The major objective in coding is to capture accurately and objectively the complete scope of information gathered. The principal obligation of the coder is to record only what the citizen said--not what the coder thinks he means. Coding is a process that must be entirely objective and replicable. This is possible with careful attention to coding procedure and training of coders.

To assure coder accuracy, reliability must be checked at regular intervals. These checks monitor how carefully the coder is following directions and objectively recording the content of input, how well instructions and directions in the codebook have been developed, and what revisions or additions to the codebook might be needed. Regular updating of instructions usually is necessary.

Coding is a demanding job, and not everyone can do it. Persons who do not rapidly acquire the necessary skill should not continue coding. Ideal coders, from the standpoints of both accuracy and cost, usually are technical and clerical staff. Personal or professional knowledge about the issue at hand is not necessary and in some cases may actually interfere with objective coding.

Coding is the process of accurately and objectively transferring the content of public input to a form that facilitates summary for use by decisionmakers.

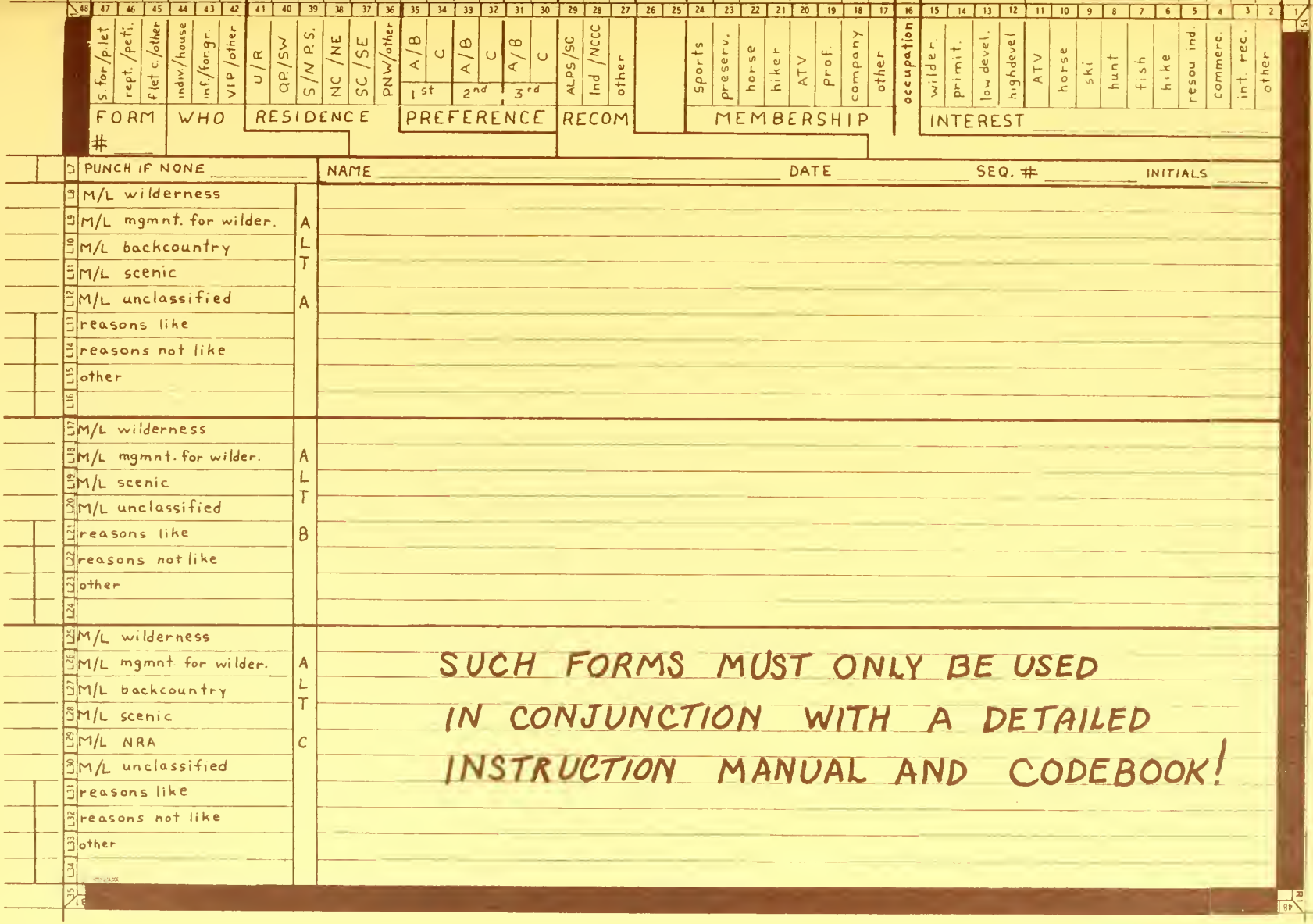


Figure 2.--Example Codinvolve summary form used on the Alpine Lakes study on the Snoqualmie National Forest in Washington State.

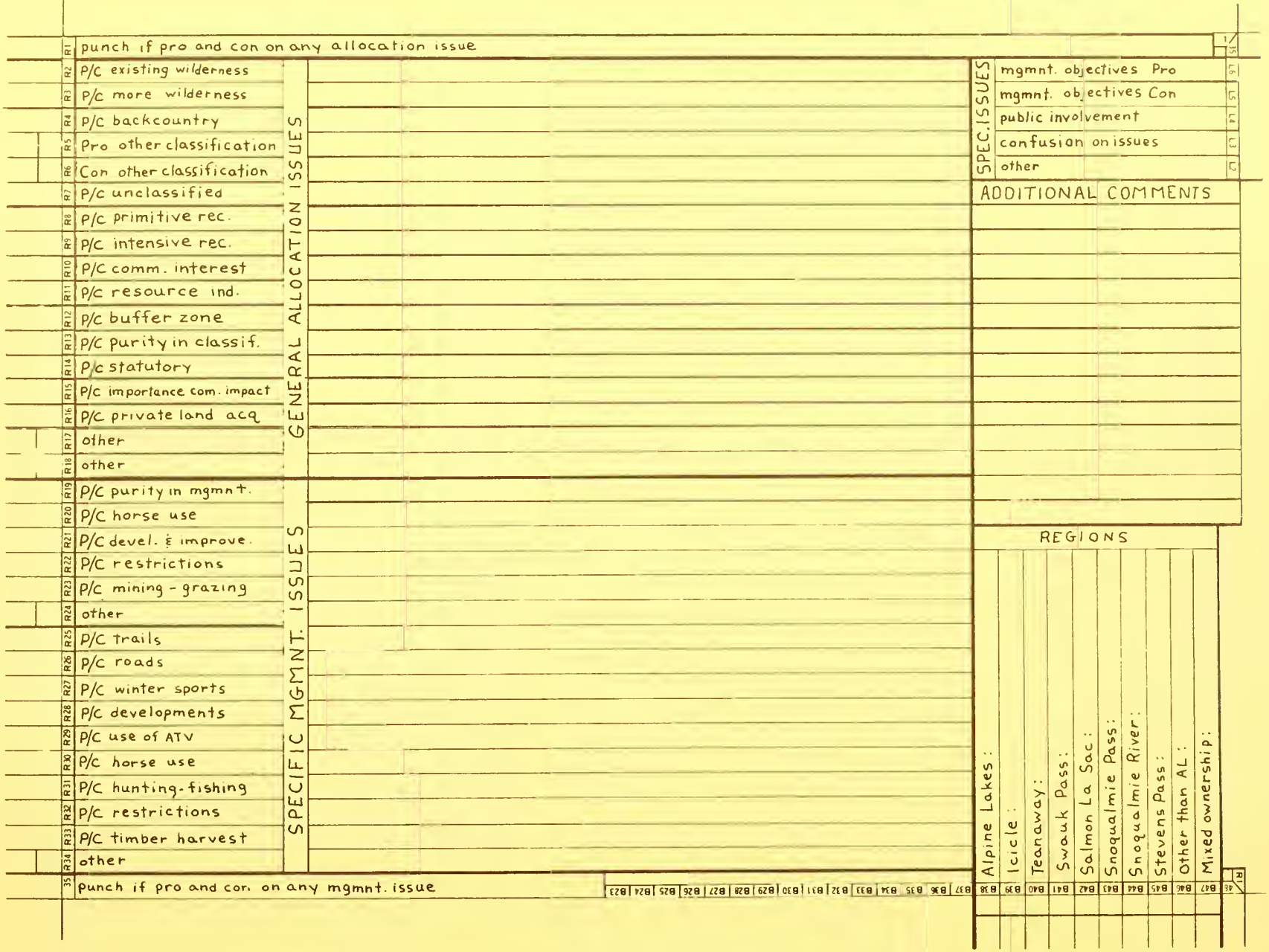


Figure 2.--Example Codinvolve summary form used on the Alpine Lakes study on the Snoqualmie National Forest in Washington State--continued.

Experience indicates that it takes at least 3 to 4 days to train a group of coders. Reliability during this period usually starts at 50 to 65 percent and rises to 90 percent or higher.

The amount of input that a coder can handle without losing a significant degree of reliability varies with individuals and with differing types of input. For fairly complex letters, average output is nearly 50 a day; beyond that number, reliability begins to decline sharply. Structured types of input are easier to code, so form letters and coupons can be handled more quickly, sometimes at a rate of nearly 150 or 200 a day. Analysts should remember that the principal concern is accuracy, not the rate.

Adequate time must be allocated for coding. If enough coders are not available, additional time will be needed to complete the job.

Experience indicates that it takes at least 3 to 4 days to train a group of coders.

5. *Organizing a report to summarize input in relation to pertinent questions (a judgment-free summary).* Upon completion of coding, the analyst is ready to summarize the information into a form easy for decisionmakers to use. Sorting usually is done either by hand (using edge-punch cards), by computer, or both. Each method is effective, but we have found the long-range retrieval potential to be far greater with hand sorting of edge-punch cards since they can be used by untrained personnel in even remote field locations.

The end product of Codinvolve is a set of tables which summarizes all public input. To answer the questions spelled out earlier, and to display the sentiment expressed by the public on other issues, analysts must organize tables which portray the data. For instance, if decisionmakers are interested in how public response regarded three alternatives, they might want tables that show how opinion varied according to form of input, residence, who responded, and so forth. It is particularly important that the analyst provide information about *all* issues discussed in the input, and not just that related to the specific, decisionmaking questions. This will insure that new or unanticipated information provided by citizens is not overlooked.

The product of a Codinvolve analysis *is not* a written report. It is the objectively interpreted display of the public input, such as shown in table 1. However, most decisionmakers will request that analysts provide more than a collection of tables. For example, they will be interested in what interpretations the analysts make of these tables, what limitations appear. Writing such reports requires that an analyst interpret the tables with great care to assure that his narrative accurately describes the data. To guard against subjective or erroneous interpretations, draft copies of the reports can be circulated to others for technical review. These reviews are invaluable in keeping interpretation accurate and incorporating points the first writer may have missed.

BUDGET AND TIME REQUIREMENTS

Analyzing the content of public input may appear deceptively easy. Often we've been asked to "drop by this afternoon to show me how it works...I want to analyze 5,000 letters tomorrow." Unfortunately, it isn't that easy to learn or to use Codinvolve. Nor is it cheap in cost or time. As with most inventory systems, learning and using Codinvolve requires some intensive effort on the part of managers, technicians, and coders. Although cost norms have not yet been established, past experience indicates that Codinvolve analysis usually runs between $1 and $2 per input.

A decision to use Codinvolve or any other system capable of providing similar information is a decision to commit funds and people. But where significant issues require the analysis of public input the benefits seem well worth the cost.

Table 1.--*A hypothetical example showing balance of opinion according to form of input with supporting reasons*[1/]

Alternative 1	Form of input				
	Letters[2/]	Petitions	Reports[2/]	Form letters	Total
For	82 (I) 90 (S)	2 (I) 83 (S)	3 (I) 3 (S)	82 (I) 86 (S)	169 (I) 262 (S)
Against	31 (I) 35 (S)	18 (I) 645 (S)	4 (I) 5 (S)	21 (I) 21 (S)	74 (I) 706 (S)

(I) = Number of inputs. (S) = Number of signatures.

[1/] Readers interested in examining actual reports based on a Codinvolve analysis are referred to:

1. "Summary of National Public Response to the Roadless Area Review Draft Environmental Impact Statement." A report by John C. Hendee and Roger N. Clark, June 1973, 53 p., mimeo. Available on request from the Director of the Division of Information and Education, U.S. Forest Service, USDA South Building, Washington, D.C. 20250.

2. "A Summary of Public Response on the Final Environmental Statement Concerning the Proposed Pelican Butte Winter Sports Development." A report by Lyle E. Jack, 24 p., mimeo. Available on request from the Forest Supervisor, Winema National Forest, U.S. Forest Service, Post Office Building, Klamath Falls, Oregon 97601.

3. "Public Response to the Olympic National Park Draft Wilderness Proposal and Master Plan--Summary and Analysis." A report by the Recreation Research Project, U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Seattle, Washington. Available on request from the Regional Director of the Pacific Northwest Region, National Park Service, 4th and Pike Building, Seattle, Washington 98101.

[2/] List of organizations submitting reports and letters is provided for every opinion discussed.

Reasons given in support of the opinions expressed

Reasons For	Reasons Against
Best for economy (151)	Already too many roads (72)
Provide jobs (111)	Need more wilderness (65)
Provide mass recreation (61)	Preserve for posterity (47)
Other alternatives too restrictive (43)	Protect areas from development (31)
Restricts intensive recreation (26)	Protect areas from timber harvest (22)
Restricts roads (19)	Protect areas from general misuse (12)
Impact on local economy (9)	Last chance (8)
Restricts timber harvest (4)	Wildlife values (3)
Enough already (1)	

CONCLUSIONS

The Codinvolve system was devised in response to increasing requests by land managers for a tool to handle the public input they receive. To satisfy the needs of decisionmakers and to protect the integrity of this input, a system was developed which meets the criteria outlined in this paper. To the extent that Codinvolve (or any other system) continues to satisfy these criteria, the results should satisfy both managers and the public they serve.

LITERATURE CITED

Frear, Samuel T.
1973. Confrontation vs. Communication: Confessions of a government PR man. J. For. 71(10): 650-652.

Hendee, John C., Robert C. Lucas, Robert H. Tracy, Jr., Tony Staed, Roger N. Clark, George H. Stankey and Ronald A. Yarnell
1973. Public involvement and the Forest Service: Experience, effectiveness and suggested direction. A report from the United States Forest Service administrative study of public involvement, U.S. For. Serv., Washington, D.C. 163 p.

Reinke, Konrad B., and Betty Reinke
1973. Public involvement in resource decisions: A National Forest seeks public input for recreation development. J. For. 71(10): 656-658.

Stankey, George H.
1972. The use of content analysis in resource decisionmaking. J. For. 70(3): 148-151.

GPO 990-616

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-224 April 1974

EVALUATION OF THE BELL 205A-1 TURBOJET HELICOPTER AND SPRAY SYSTEM FOR FOREST APPLICATION OF INSECTICIDE

by

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ABSTRACT

The atomization and distribution of insecticide sprays produced from a Bell 205A-1 turbojet helicopter and spray system were evaluated under open ground conditions. The degree of atomization was within the same range as that produced by the smaller helicopters, and the acceptable swath width was wider. In some flights there were two very high deposit peaks with low deposit between those peaks, similar to that produced by a fixed-wing aircraft spraying at a low height above the ground. By visual observation, the main rotor vortexes appeared stronger and more pronounced than those of smaller helicopters. On a large forest spray program the Bell 205A-1 sprayed an average of 877 acres per hour at an application rate of 1 gallon per acre for a cost of $1.78 per acre.

KEYWORDS: Helicopters, pesticide application methods.

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INTRODUCTION

In recent years, the use of helicopters for forest pesticide application has increased. Most use, however, has been on small acreages and with small helicopters such as the Bell 47 series and Hiller 12E series. These small aircraft spray at speeds between 45 and 60 miles per hour and carry loads between 30 and 120 gallons depending on the density of the pesticide and altitude of operation. They can operate from small clearings close to the area being treated and are an excellent tool for treating small and irregular areas because of their maneuverability and slow speed. Where large acreage is to be sprayed, these helicopters are generally considered to be economically unsuitable because of their small payload.

An aerial spray test, to control the Douglas-fir tussock moth with the insecticide Zectran, over several thousand acres was planned for June 1973. The size of the test area was too large for the smaller conventional helicopters; therefore a larger helicopter, the Bell 205A-1 turbojet, was considered.

In the Northwest States, the Forest Service is currently using the Bell 205A-1 turbojet for transporting cargo and personnel, rappelling fire crews, and dropping water on fires. There were no spray data available for the 205A-1; however the helicopter was available locally, and the Forest Service initiated an evaluation of it for possible use on the Zectran spray test.

This was a cooperative study between the Pacific Northwest Forest and Range Experiment Station and Region 6, Insect and Disease Control Branch, of the U.S. Forest Service.

DESCRIPTION OF SPRAY SYSTEM

The helicopter and spray system (fig. 1A) were furnished and operated by Evergreen Helicopters, Inc., of McMinnville, Oregon.[2/] The helicopter was a Bell 205A-1, with a 1,400-horsepower gas turbine engine which has a 4,000-pound lifting capacity and cruises at 110 knots. The spray system (fig. 1B and 1C) was designed for Evergreen Helicopters, Inc., by Agrinautics of Las Vegas, Nevada. The internally mounted system consisted essentially of a 400-gallon fiberglass spray tank, a 25-horsepower gasoline engine with a direct drive pump, and left and right spray booms. The spray tank was mounted on an aluminum frame which was secured to the floor utility studs.

[2/] The use of trade, firm or corporation names is for the information and convenience of the reader. Such use does not constitute endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

A

B

C

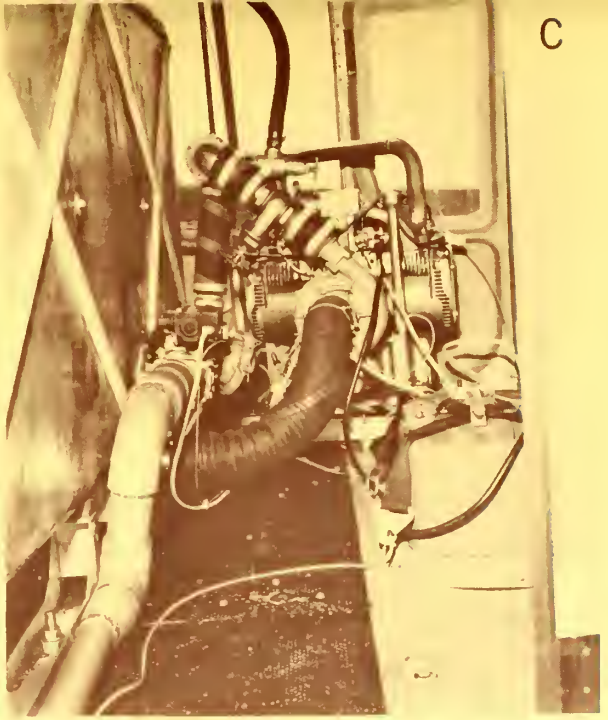


Figure 1.--Bell 205A-1 helicopter and spray system: A, helicopter. B and C, spray system.

The tank could be filled from either side of the helicopter. The pump was driven by a 25-horsepower Onan gasoline engine. The pump and engine were secured to the floor utility studs as a unit. The pump was capable of pumping 300 gallons per minute at 100 pounds per square inch and maintain recirculation within the spray tank. A master control box was installed in place of the pilot's map case. The master control box included a throttle, RPM gage, pump pressure gage, circuit breaker switch, start switch, and master ignition switch. There was also a boom pressure gage mounted on the right-hand side of the instrument panel. The boom on-off valve was controlled by a switch mounted on the pilot's cyclic stick. Fluid lines between the pump and tank were of a high pressure rubber type. A 12-volt battery was used for starting the pump engine and recharged by the aircraft engine generator. Both spray booms (left and right) were 24 feet long and reduced from a diameter of 2 inches to 1-1/2 inches at a point 12 feet, 6 inches outboard. The boom was made of aluminum alloy, and each side supported by three aluminum tubes and three stainless steel cables leading from the airframe hard points to a triangular brace plate which was attached to the midsection of each boom. These brace plates caused drooling whenever nozzles were placed near them. To prevent drooling, nozzles were not placed within 18 inches on either side of these plates. There were ports on each boom (left and right) for 51 nozzles spaced 5 inches apart. Because the spray system was internally mounted and the crossover line to the left and right booms was located inside the ship, there was no port for nozzles over a 12-foot, 8-inch midsection. All nozzles were Spraying Systems diaphragm teejet with flat spray tips. The booms could be rotated to adjust the nozzle orientation with respect to the direction of flight. There was no emergency dump on this system.

TEST PROCEDURE

The purpose of these tests was to obtain data concerning the swath width and pattern produced by the 205A-1 helicopter and spray system when spraying at different airspeeds and spray heights, and to determine the degree of atomization of sprays recovered from this system using different sizes of nozzle tips. The variables tested were: (1) Spraying Systems flat spray tips No. 8002, 8010, and 8020, (2) spraying heights of 50, 100, and 200 feet, and (3) spraying speeds of 50, 70, and 90 miles per hour.

The spray formulation was the same as that used for the insecticide Zectran, except that there was no active ingredient. This formulation consisted of nine parts of #2 fuel oil mixed with one part Dowanol TPM (tripropylene glycol methyl ether). To each gallon of spray, 3.785 grams (0.1 percent weight to volume) of the fluorescent tracer Rhodamine B Extra base (GAF Corp.) was added to facilitate deposit assessment.

Initially the spray system was calibrated at a spray pressure of 60 pounds per square inch for an application rate of 1 gallon per acre using an assumed swath width of 200 feet. To determine if the spray was being delivered at equal rates throughout the boom, flow rates were established for each nozzle size at two inboard and two outboard positions on the boom. The formulation was sprayed through the nozzles and collected for 1 minute, then measured in a graduate cylinder thus providing the flow rate per minute. All nozzles were oriented forward and down at 45 degrees with respect to the line of flight. The nozzle arrangement on the boom for each treatment parameter is shown in figure 2.

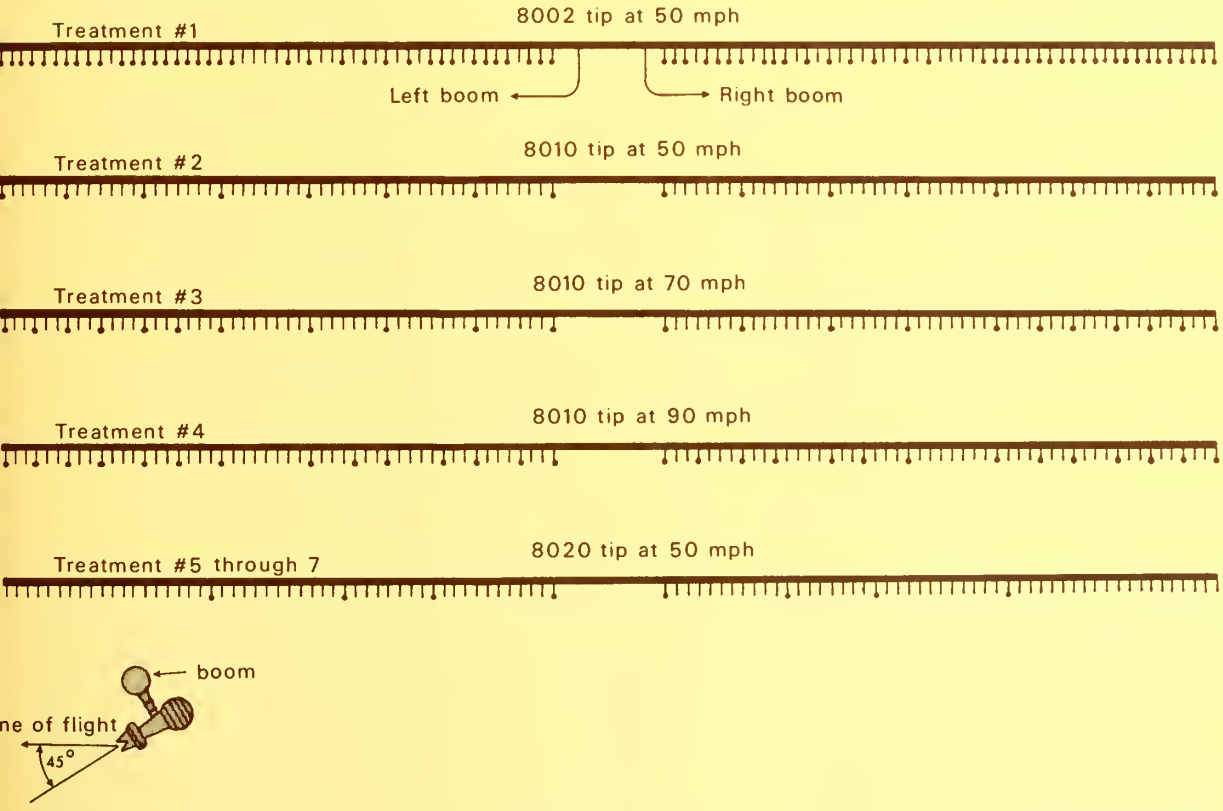


Figure 2.--Schematic diagram showing the nozzle arrangement on the boom for each treatment parameter.

The procedure used for determining the spray distribution was similar to that reported by Isler and Yuill (1964) for fixed-wing aircraft and by Isler and Maksymiuk (1961) for helicopters. A 500-foot rotating platform shown in figure 3 was used for holding the deposit sampling surfaces. One 6- by 6-inch aluminum plate and one white 4- by 5-inch Kromekote card were positioned at 10-foot intervals along the entire length of the platform. The platform was rotated for each test flight until it was perpendicular to the prevailing wind. The aircraft was flown upwind over the platform at a predetermined spot and at a designated speed and altitude. The spray was turned on 500 feet downwind of the platform and off 1,500 feet upwind of the platform. After turning off the spray, the pilot continued in a straight line for 5 seconds, then made a large turn and landed downwind of the platform so that the air currents in the direct vicinity of the sampling stations would not be disturbed.

Figure 3.--A 500-foot rotating platform for sampling aerial spray deposit.

The meteorological conditions were monitored for each test flight, as shown in table 1. Most flights were made in the early morning, when spraying conditions are usually favorable. There was a total of 32 test flights, of which 9 were discarded because the wind changed direction during flight and blew off a large part of the spray from the edge of the platform.

The spray was allowed to settle for 15 to 20 minutes; then the deposit sampling surfaces were collected and placed in slotted boxes to prevent smudging of drops and contamination of one surface by another. The boxes were then transported to the laboratory for analysis.

The spray drops on the white Kromekote cards were counted and sized using an ultraviolet illuminator and dissecting microscope. The spray atomization was determined by the drop-size spectra method (Maksymiuk 1964). The number of drops are expressed in number per square centimeter of surface area, and the size (atomization) is expressed as the volume median diameter (vmd). 3/

3/ Volume median diameter (vmd) is the drop diameter satisfying the requirement that half of the volume of liquid is in drops smaller and half is in drops larger than the vmd.

Table 1.--*Summary of meteorological data*

Flight number	Date (1973)	Time (a.m.)	Wind conditions		Temperature (°F)			Relative humidity	Sky condition
			Miles per hour	Gusty	At 2 feet	At 4 feet	At spray height		
								Percent	
3	3-30	5:54	3	no	44.5	45	42.8	88	overcast
4	3-30	6:28	2-3	yes	45	45	42.8	88	overcast
5	3-30	8:15	2-3	yes	45.5	46	44.6	87	overcast
6	3-30	8:40	2-3	mildly	45.5	46	44.6	88	overcast
8	4-2	6:10	1	no	27.5	28	30	88	clear
9	4-2	6:37	2-3	no	29.5	30	30	87	clear
10	4-2	6:55	1	no	35	34	32	80	clear
12	4-2	8:15	3-4	mildly	40	39	39.2	80	clear
13	4-2	9:15	5-6	yes	46.5	48	39.2	77	clear
14	4-2	10:38	--	slightly	52	52	41	59	clear
15	4-3	6:41	1	no	37	36	30	78	clear
16	4-3	7:24	1-2	no	43	42	35.6	76	clear
17	4-3	8:00	0-1	no	53	51	39.2	57	clear
20	4-4	5:43	2	no	34.5	35	37.4	90	clear
23	4-4	7:31	0.5	no	44	43	42.8	80	clear
24	4-4	8:00	0.5	no	48	45	44.6	78	clear
25	4-4	8:36	1-2	no	50	48	46.4	77	clear
26	4-4	9:08	2-4	yes	51	50	50	75	clear
27	4-4	9:45	0.5	mildly	54	53	53.6	60	clear
29	4-4	10:55	3-4	yes	62	61	57.2	52	clear
30	4-6	5:50	2	no	33	34	--	95	clear
31	4-6	6:18	2	no	34	35	--	95	clear
32	4-6	7:30	4-5	yes	46	45	--	86	clear

The spray deposit was washed from each of the aluminum plates with 10 milliliters of 95-percent ethanol. The deposit recovered from the plates was quantitated fluorometrically, using a Model 430 Turner Spectrofluorometer, similar to the method described by Yates and Akesson (1963). The quantity of spray is expressed in gallons per acre (gpa).

RESULTS AND DISCUSSION

Calibration

Flow rates for each of the nozzle tip sizes at the different locations along the boom are shown in table 2. Even though there was some variation at different locations along the boom, there was no particular location that was consistently high or low. The spray material seemed to be displaced throughout the boom at nearly equal rates. The gasoline-driven spray pump, which is independent of the helicopter engine, allowed for easy calibrations on the ground.

Swath Width

Table 3 is a summary of the mean swath width, swath deposit, percent recovery, and atomization for each treatment. A comparison of nozzle tip sizes (treatments 1, 2, and 5) shows that the larger tips produced wider acceptable swaths. For our purpose an acceptable swath width was defined as that portion of the swath having a deposit level of 0.1 gpa or greater at each sampling point throughout the swath. The smallest nozzle tips (treatment 1) produced the finest atomization which drifted farther and resulted in

Table 2.--*Summary of flow rate data for nozzles positioned at various points along the boom*

Location of nozzle	Spray pressure	Mean flow rate (gallon per minute)[1/]		
		Nozzle tip 8002	Nozzle tip 8010	Nozzle tip 8020
	Pounds per square inch			
Left inboard	60	0.26	1.37	2.58
Left outboard	60	.26	1.34	2.61
Right inboard	60	.29	1.33	2.38
Right outboard	60	.30	1.41	2.57
Mean		.28	1.36	2.53

[1/] There were three replications per nozzle size per location.

Table 3.--*Summary of the mean swath width, swath deposit, percent recovery, and atomization for each treatment*

Treatment	Number of flights	Nozzle		Spraying		Swath width[1]	Swath deposit		Percent recovery	Atomization, vmd
		Tip size	Number	Height	Speed		Gallon per acre[2]	Drops per square centimeter		
				Feet	*Miles per hour*	*Feet*				*Microns*
1	5	8002	74	50	50	160	0.178	90	19	106
2	4	8010	16	50	50	295	.309	86	48	147
3	5	8010	22	50	70	186	.365	54	33	144
4	2	8010	28	50	90	175	.420	111	44	126
5	3	8020	8	50	50	297	.240	34	38	[3]183
6	3	8020	8	100	50	273	.361	53	55	184
7[3]	1	8020	8	200	50	240	.332	21	43	179

[1] The swath width is that part of the swath having 0.1 gallon per acre or greater at each sampling point.

[2] At a nozzle pressure of 60 pounds per square inch.

[3] No replications.

a wider overall swath, but a large portion of those swaths had a deposit level lower than that which was acceptable. It should be pointed out that all of the flights were single passes and the lower level of deposit at the edges of the swath would be filled in by adjoining swaths under normal spray operations.

A comparison of swath width for the 50-, 70-, and 90-miles-per-hour flying speeds, using the same nozzle (treatments 2, 3, and 4, respectively), shows the same trend as with different size nozzles at one speed. The faster flying speeds produced a finer atomization which resulted in narrower acceptable swath widths. This similarity is to be expected since both methods change the degree of atomization.

There was some difficulty in assessing the effect of spraying height on the swath width (treatments 5, 6, and 7). As the spraying height was increased, it became more difficult to catch the entire spray swath on our 500-foot sampling platform due to drifting. The acceptable swath width was widest at the lowest (50-foot) flying height. This is contrary to what one might expect; however, we suspect that due to the tremendous rotor downwash from this aircraft, there is a cushioning effect at ground level causing the spray to bellow out from the center of flight. When the airspeed or the flying height is increased, the effect of rotor downwash at ground level is lessened (USDA Forest Service 1969).

In forest spraying operations, this downwash and rotor wake may be advantageous since there would be very little, if any, cushioning effect. The downwash may enhance spray penetration and deposition on the foliage or insect.

Spray Deposit and Pattern

Data from several of the flights were discarded because a large portion of the spray drifted off the platform. Most of the replicated flights showed large variations in spray patterns, deposit, and recovery levels, making it difficult to establish whether these differences were a result of the aircraft and spray system or the meteorological conditions during the flight. Figures 4-10 show the spray pattern of individual flights for each treatment parameter. Under upwind flight conditions, the 205A-1 produced two very high peaks with a ɔw cradle between, similar to that of small fixed-wing aircraft flying at low elevation (Chamberlin et al. 1955, Isler and Yuill 1964). Small helicopters produce these same peaks and cradles but they are not as extensive (Isler and Maksymiuk 1961). Based on visual observations, the 205A-1 produced larger, more pronounced vortexes than the small helicopters, which could account for the more accentuated peaks and cradles. The mean deposit level in terms of gpa and drops per square centimeter for the entire swath varied considerably between the various treatment parameters (table 3). But then so did the swath widths on which these averages were based, as shown by the individual flight data in table 4. The narrower the swath, the higher the deposit level, assuming the spray was not lost to the atmosphere and the treatment parameters were the same.

Treatments 2 and 4 appear to give the best coverage. These treatments gave the higher degree of recovery, considering the swath deposit in terms of gpa and number of drops per square centimeter. Both of these treatments have atomizations within the 125-150-micron vmd range. Treatment 6 might appear to be the best since the swath width is wide, the deposit level in terms of gpa is high, and the degree of recovery is high. But treatment 6 is actually less desirable than treatments 2 and 4 because of the fewer drops per square centimeter, which is a result of the larger vmd (184 microns). This is not to say that treatment 6 would not be better in certain situations, such as under conditions which would prevent the smaller droplets from being deposited on the target, or where the smaller droplets did not contain enough active ingredient to give a high degree of mortality.

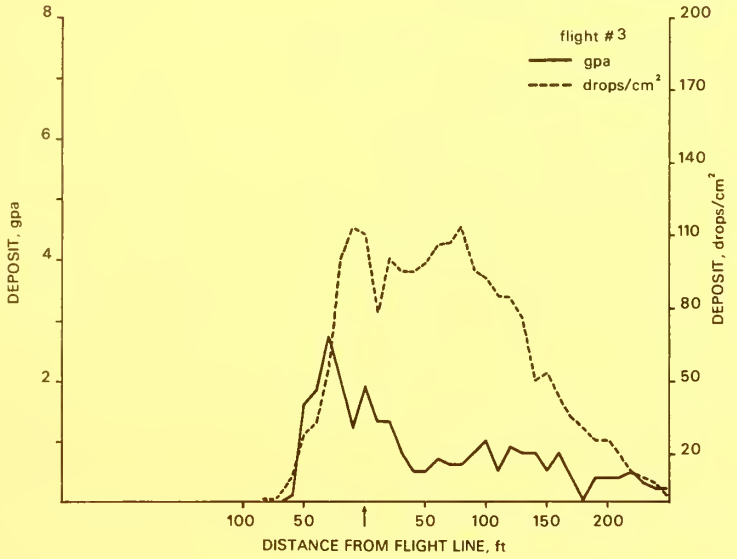
Table 4.--*Swath width, swath deposit, percent recovery, and atomization for individual test flights*

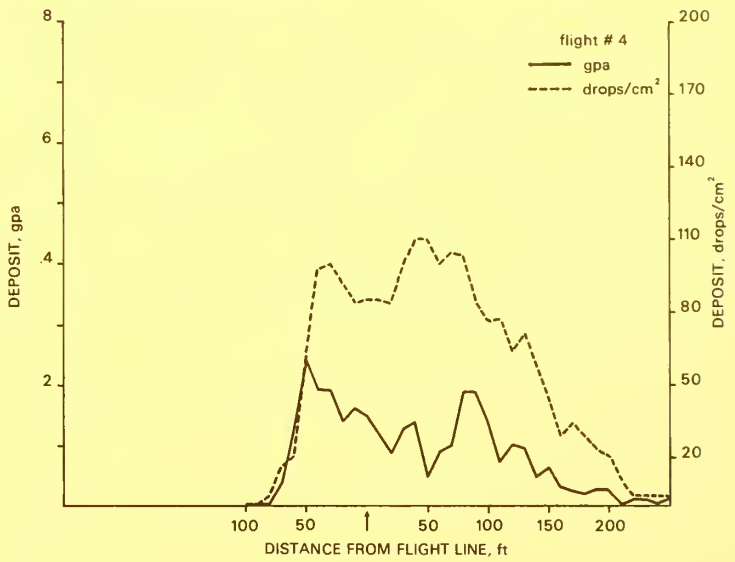
Treatment	Nozzle		Spraying		Flight number	Swath width[1]	Average swath deposit		Percent recovery	Atomization, vmd
	Tip size	Number	Height	Speed			Gallon per acre[2]	Number of drops per square centimeter		
			Feet	*Miles per hour*		*Feet*				*Microns*
1	8002	74	50	50	3	70	0.192	76	14	
					4	180	.137	87	15	
					5	140	.175	98	20	
					6	240	.189	91	23	101
					32	170	.195	98	23	112
					Mean	160	.178	90	19	106
2	8010	16	50	50	8	280	.334	78	50	152
					9	280	.350	77	52	
					10	270	.321	126	48	
					12	350	.232	62	42	142
					Mean	295	.309	86	48	147
3	8010	22	50	70	13	320	.202	66	34	
					14	180	.176	54	19	
					15	110	.608	69	39	141
					16	180	.357	36	38	
					30	140	.483	45	37	147
					Mean	186	.365	54	33	144
4	8010	28	50	90	17	180	.483	165	53	132
					31	170	.357	57	34	119
					Mean	175	.420	111	44	126
5	8020	8	50	50	26	310	.247	37	41	
					27	270	.280	34	41	183
					29	310	.193	30	32	
					Mean	297	.240	34	38	183
6	8020	8	100	50	23	250	.409	59	60	182
					24	300	.347	54	57	187
					25	270	.326	46	49	
					Mean	273	.361	53	55	184
7	8020	8	200	50	20	240	.332	21	43	179

[1] The swath width is that part of the swath having 0.1 gallon per acre or greater at each sampling point.

[2] At a nozzle pressure of 60 pounds per square inch.

Figure 4.--Spray pattern for individual flights -- treatment 1: 8002 nozzle tip, 50-foot spraying height, 50 miles per hour.





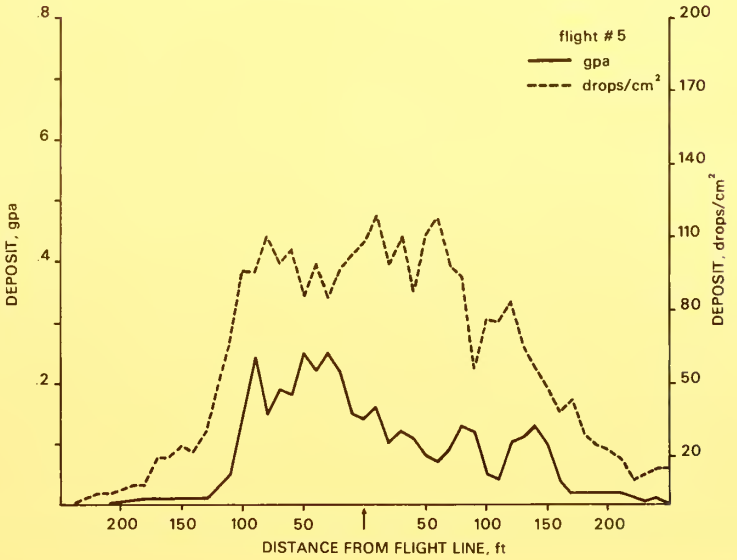
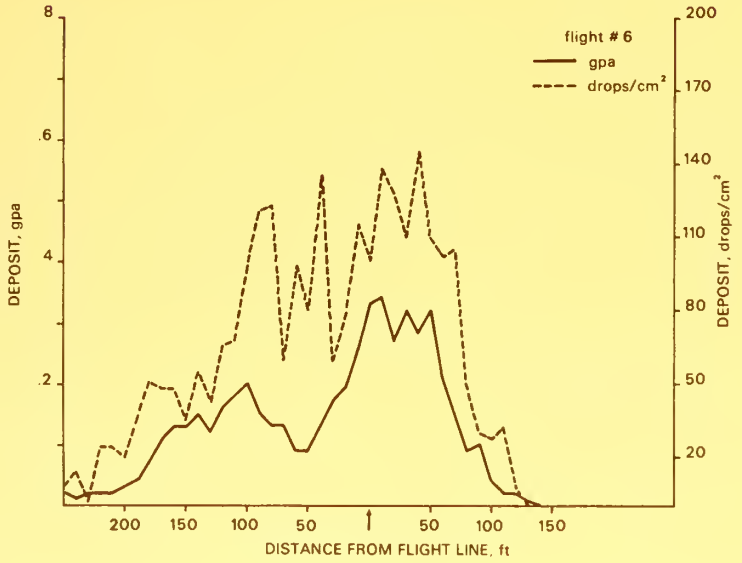


Figure 4.--Spray pattern for individual flights -- treatment 1: 8002 nozzle tip, 50-foot spraying height, 50 miles per hour (continued).



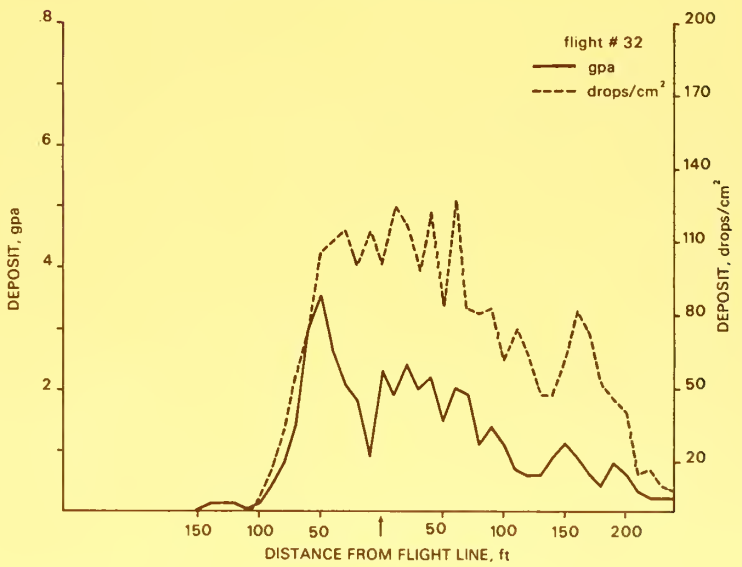
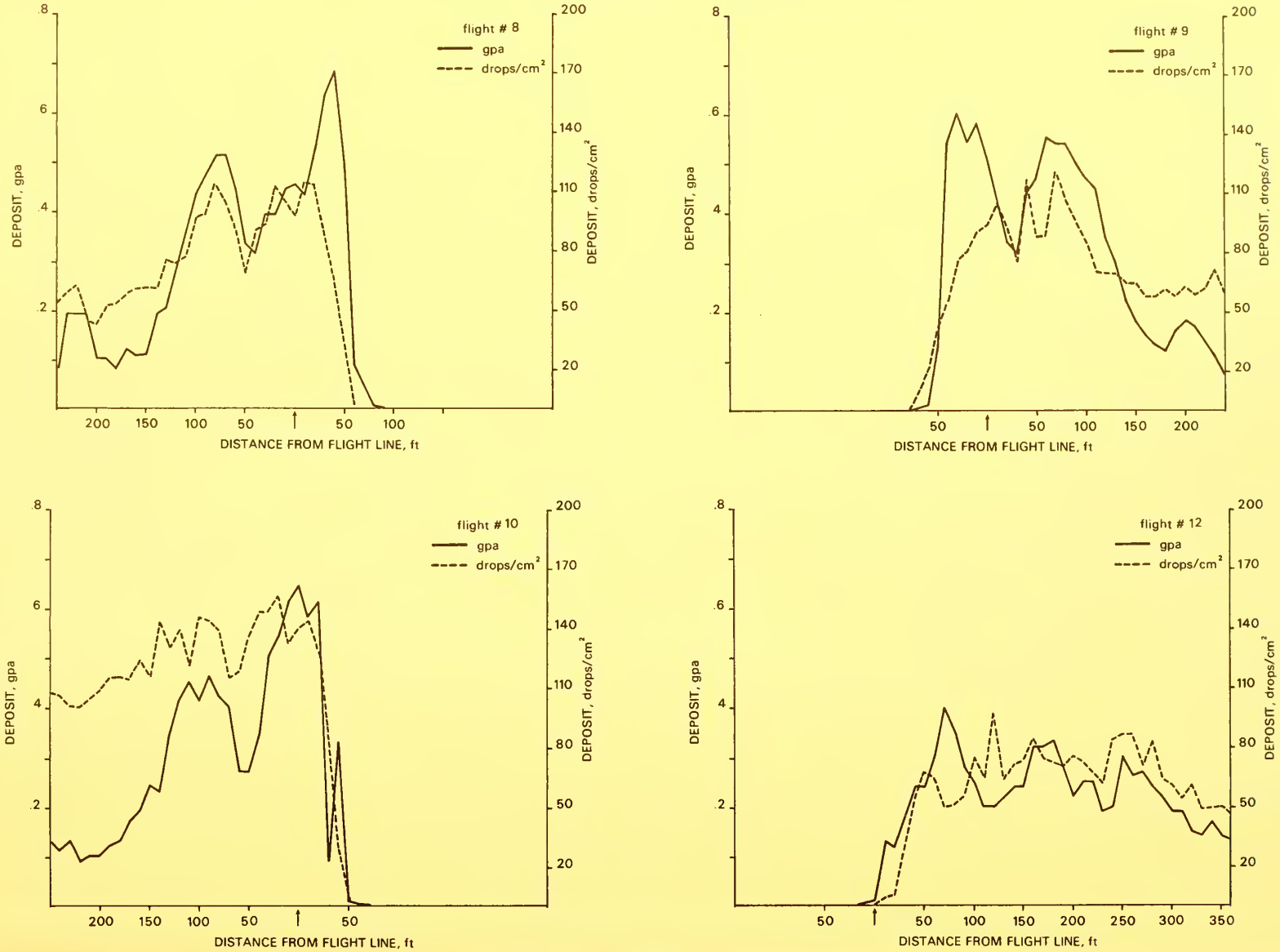
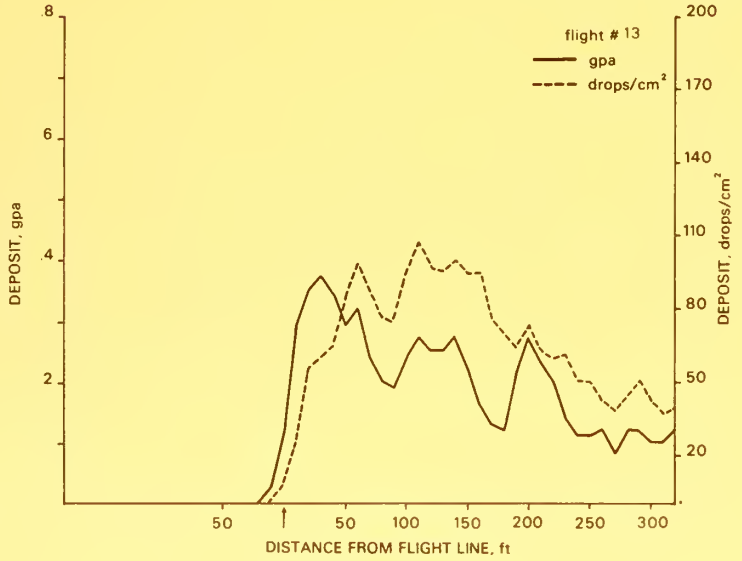
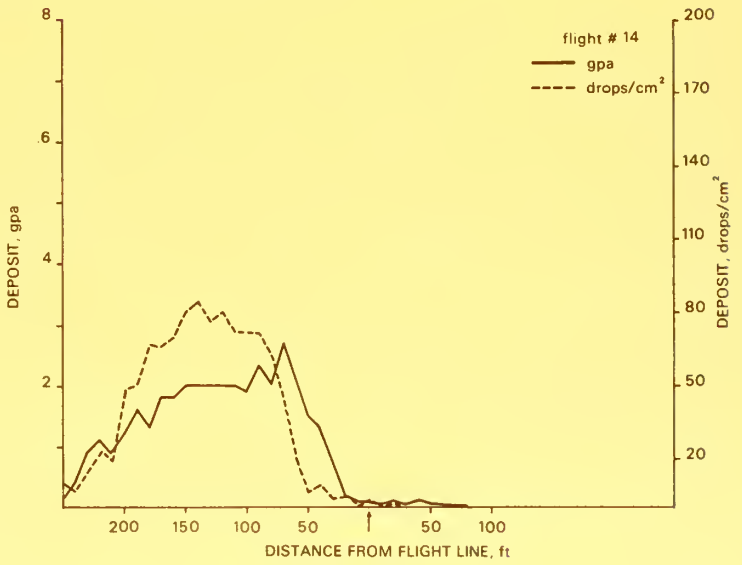


Figure 5.--Spray pattern for individual flights -- treatment 2: 8010 nozzle tip, 50-foot spraying height, 50 miles per hour.



50-foot spraying height, 70 miles per hour.





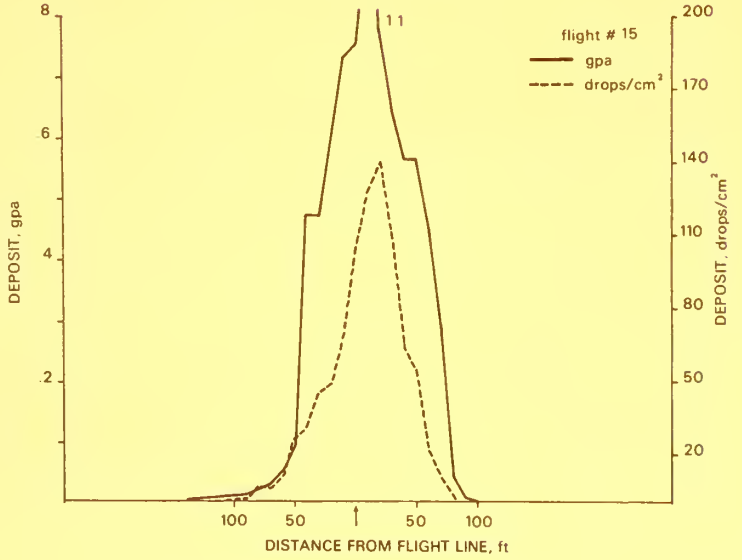
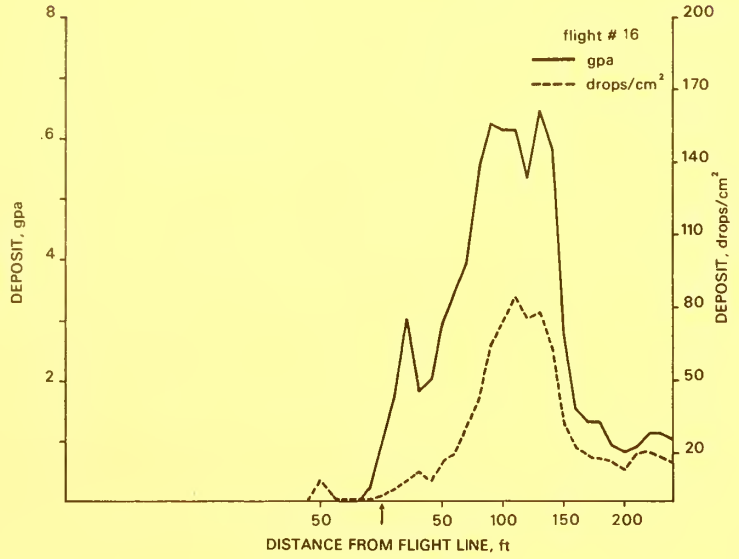


Figure 6.--Spray pattern for individual flights -- treatment 3: 8010 nozzle tip, 50-foot spraying height, 70 miles per hour (continued).



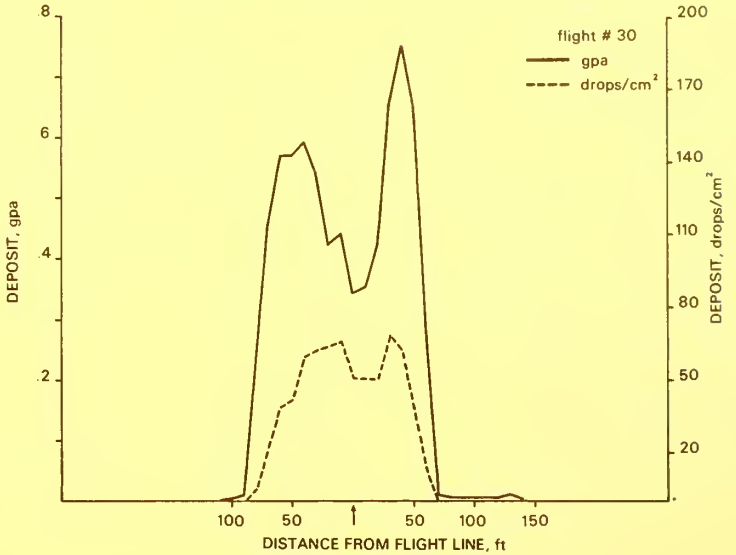
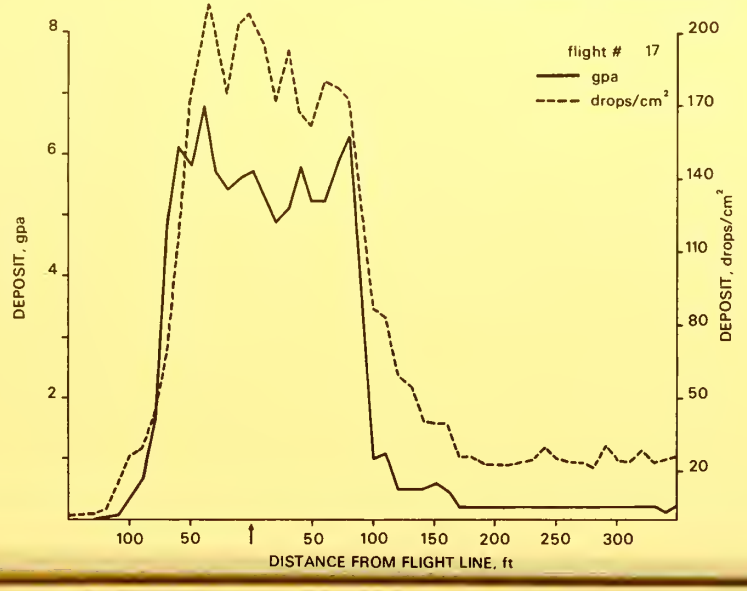


Figure 7.--Spray pattern for individual flights -- treatment 4: 8010 nozzle tip, 50-foot spraying height, 90 miles per hour.



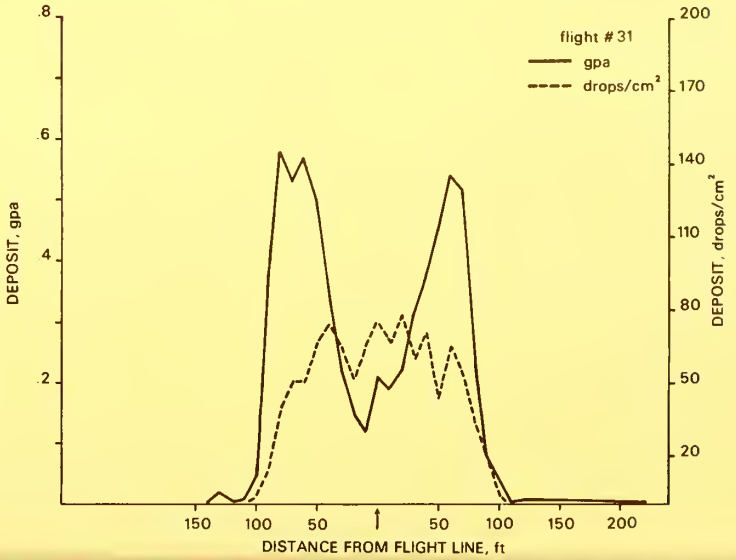
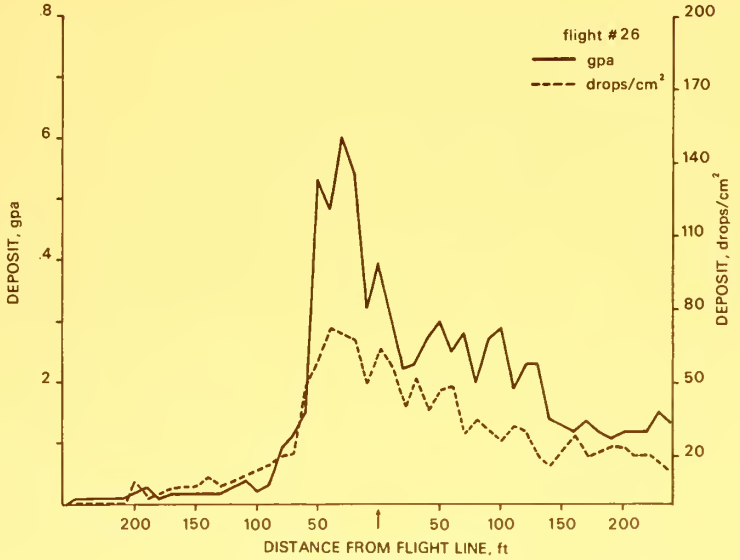
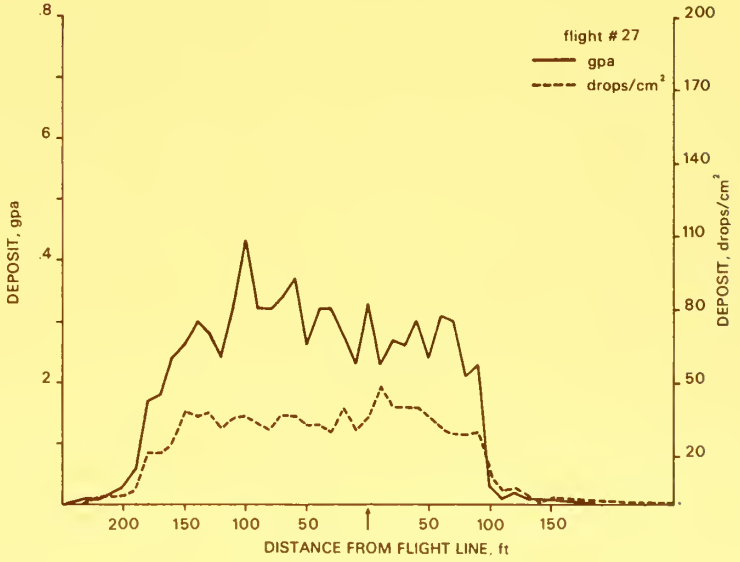


Figure 8.--Spray pattern for individual flights -- treatment 5: 8020 nozzle tip, 50-foot spraying height, 50 miles per hour.





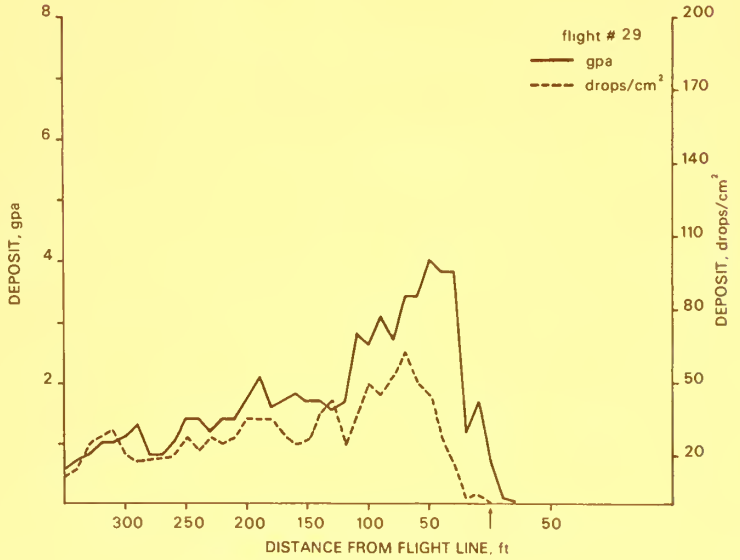
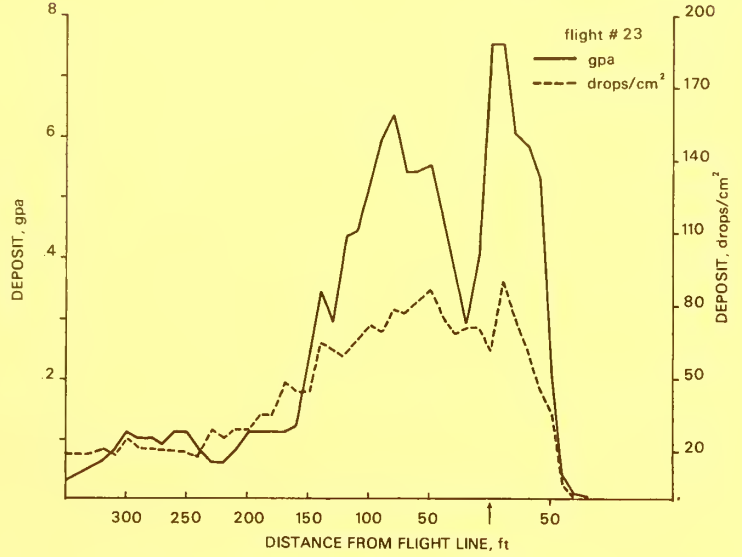
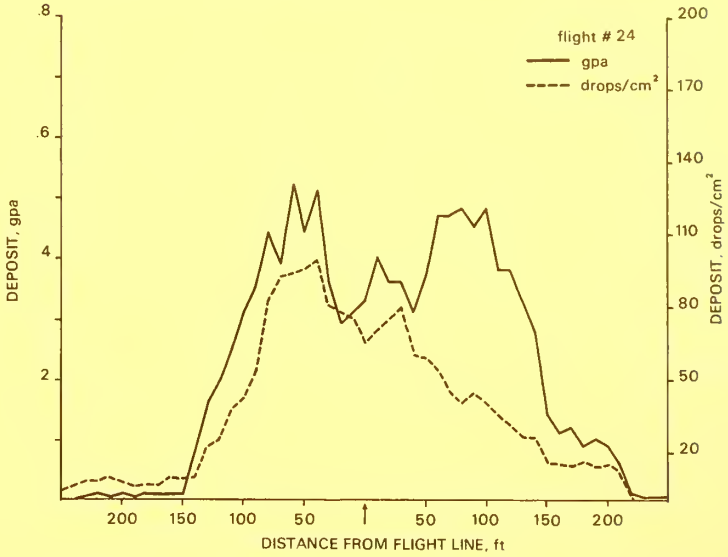


Figure 9.--Spray pattern for individual flights -- treatment 6: 8020 nozzle tip, 100-foot spraying height, 50 miles per hour.





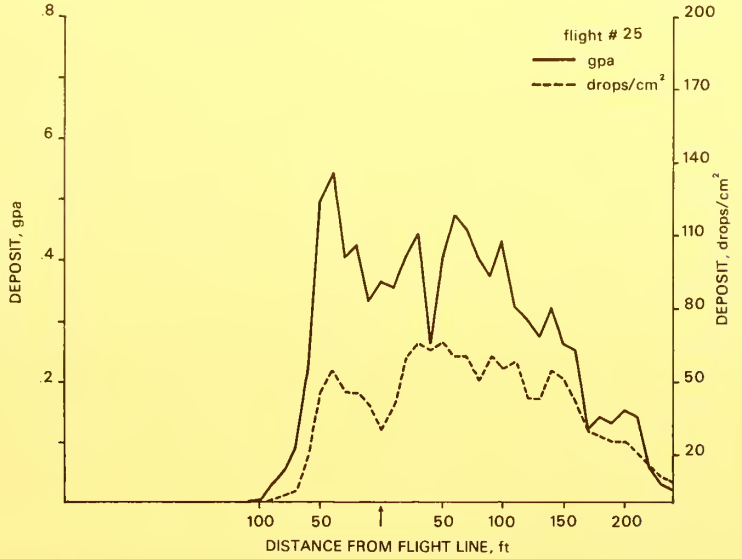
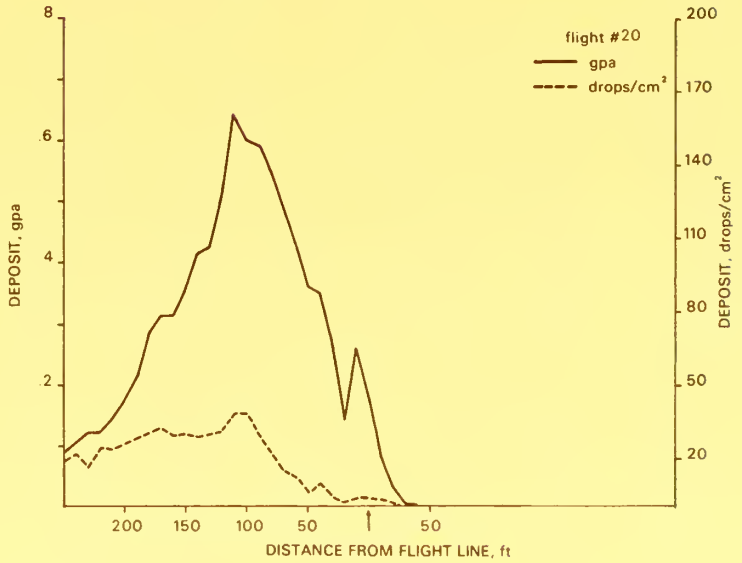


Figure 10.--Spray pattern for individual flights -- treatment 7: 8020 nozzle tip, 200-foot spraying height, 50 miles per hour.



Spray Recovery and Atomization

Table 3 shows that there was an average of only 40 percent of the spray recovered from the 205A-1, and, generally speaking, there was a higher level of deposit recovered from those flights having the larger atomization. There is no obvious explanation for this low recovery level. For open-ground tests, using an oil-base formulation, an average of 73 percent of the spray was recovered from a Bell 47D series helicopter (Isler and Maksymiuk 1961), 75 percent was recovered from a Piper PA-18A (Isler and Yuill 1964), and 76 percent was recovered from a Stearman (Isler and Yuill 1963).

The atomizations observed are in the range produced by aircraft operating under similar treatment parameters (unpublished data). There appears to be no unusual effect on atomization created by the 205A-1.

PERFORMANCE OF THE BELL 205A-1 UNDER FOREST SPRAYING CONDITIONS

Following completion of the airport test, it was concluded that the 205A-1 could be used for aerial application of Zectran for forest insect control. Accordingly, two Bell 205A-1 helicopters were used for the 1973 Douglas-fir tussock moth operational test in northeastern Oregon and southeastern Washington. Before spraying, the helicopters were calibrated to deliver 1 gpa at a speed of 90 miles per hour and a swath width of 200 feet using Spraying Systems TeeJet flat fan nozzle tips No. 8020 at 60 pounds per square inch and later changing to 45 pounds per square inch. The average load at 3,000- to 5,000-foot elevation was 250 gallons and the minimum loading time was 3 minutes with an average of 4 minutes. The average speed while ferrying was 120 miles per hour. The atomization of spray recovered at ground level at two different spray areas was 211 and 226 microns, vmd. Additional performance data are given in table 5.

Table 5.--*Field performance data of two Bell 205A-1 helicopters used in an operational insecticide spray test*

Item	Aircraft number		Average
	50-R	57	
Acres sprayed	63,718	52,545	58,132
Flight hours[1/]	73' 50"	58' 47"	66' 18"
Acres per hour[1/]	863.4	893.6	876.8
Flight days	29	25	27
Acres per flight day	2197.2	2101.8	2153.0
Hours per flight day	2.54	2.35	2.46
Cost per flight hour[1/]	$1,759.81	$1,319.85	$1,564.71
Cost per acre[2/]	$2.038	$1.477	$1.785

[1/] Includes ferrying time.

[2/] Cost includes ferrying time but does not include standby time or insecticide costs.

CONCLUSIONS

1. There was no practical difference in flow rate between nozzles placed at various locations on the boom.
2. The spray system was very easy to calibrate, there was good agitation in the tank, and the boom could be rotated to adjust nozzle orientation with respect to the line of flight.
3. The vortexes appeared to be much stronger and much more pronounced than those of smaller helicopters.
4. The system produced larger than normal deposit peaks and valleys, which may possibly be explained by the absence of nozzles over a 12-foot, 8-inch center section of the boom or by the very strong rotor wake and downwash.
5. The largest of the three nozzle tips tested produced the widest acceptable swath width.
6. By increasing the spraying height from 50 feet to 100 and 200 feet, the spray is dispersed over a larger area reducing the acceptable swath width and the pilot's control over where the spray is deposited.
7. The swath widths produced by this aircraft and the spray system were definitely larger than those of a smaller helicopter.
8. This aircraft should be further tested to establish the effect of rotor wake, vortexes, and downwash on dispersal of the spray under open ground and forest conditions.

LITERATURE CITED

Chamberlin, Joseph C., Charles W. Getzendaner, Harold H. Hessig, and V. D. Young

1955. Studies of airplane spray-deposit patterns at low flight levels. U.S. Dep. Agric. Tech. Bull. No. 1110, 45 p., illus.

Isler, D. A., and Bohdan Maksymiuk

1961. Some spray distribution and atomization tests with a helicopter. U.S. Agric. Res. Serv. ARS 42-54, 9 p., illus.

_____ and J. S. Yuill

1963. Spray distribution patterns from a Stearman airplane flying at 50 feet. U.S. Agric. Res. Serv. ARS 42-82, 22 p., illus.

_____ and J. S. Yuill

1964. Spray distribution patterns from a Piper PA-18A airplane flying at 50 feet. U.S. Agric. Res. Serv. ARS 42-88, 17 p.

Maksymiuk, Bohdan

1964. The drop size spectra method for estimating mass median diameter of aerial sprays. USDA For. Serv. Res. Pap. WO-1, 9 p.

USDA Forest Service

1969. Helicopter rotor downwash effects. U.S. Dep. Agric., For. Serv. Equip. & Dev. Cent., San Dimas, Calif., ED & T 1818, 13 p.

Yates, W. E., and N. B. Akesson

1963. Fluorescent tracers for quantitative microresidue analysis. Am. Soc. Agric. Eng. Trans. 6: (2) 104-107, 114.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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USDA FOREST SERVICE RESEARCH NOTE

PNW-225 May 1974

SUSCEPTIBILITY OF 10 SPRUCE SPECIES AND HYBRIDS TO THE WHITE PINE WEEVIL (=SITKA SPRUCE WEEVIL) IN THE PACIFIC NORTHWEST

R. G. Mitchell, N. E. Johnson, and K. H. Wright 1/

ABSTRACT

Ten different species and hybrids of spruce (*Picea* spp.) were studied on 3 plots for some 16 years to determine their growth rate and susceptibility to the white pine weevil (*Pissodes strobi*) along coastal Oregon and Washington. Conclusions were that Norway spruce (*P. abies*) and Lutz spruce (*P.* X *lutzii*) grow well in the coastal environment, but Lutz spruce (*P.* X *lutzii*), because of its low susceptibility to weevil attack, is the more promising replacement for the heavily weeviled Sitka spruce (*P. sitchensis*). Norway spruce was very susceptible to the weevil. Light weeviling was also observed on black spruce (*P. mariana*), white spruce (*P. glauca*), and Engelmann spruce (*P. engelmannii*).

Keywords: White pine weevil (*Pissodes strobi*), spruce (*Picea*).

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INTRODUCTION

Sitka spruce (*Picea sitchensis* (Bong. Carr.)) is one of the most rapidly growing conifers in the Pacific Northwest (Ruth 1958). It also has good pulping characteristics, considerable resistance to animal browsing, and above average tolerance for competing brush. Currently, though, the tree is in disfavor among forest-land managers in Oregon and Washington because of damage caused by the terminal-killing white pine weevil (*Pissodes strobi* (Peck)), formerly known as the Sitka spruce weevil (*P. sitchensis* Hopkins) (Wright 1960).[2/]

The weevil attacks spruce terminals in the spring, about the time of bud burst. Eggs are laid in the bark along the terminal, with most just below the expanding buds (Johnson 1965). Hatching larvae mine downward in the cambial region, usually killing the entire terminal as well as the developing new growth. Adults emerge in midsummer, overwinter in the tree crowns, and attack terminals of other trees the next spring (Gara et al. 1971). Some adults may live and reproduce for as long as 4 years (McMullen and Condrashoff 1973).

When a terminal is killed, one or more laterals assume apical dominance (fig. 1). Impact of the weevil is thus reflected in poor tree form due to crooks in the main stem, as well as height and volume losses. Height and volume loss is magnified because the weevils show a preference for trees with the longest terminals. Trees with leaders less than 12 inches (30.5 cm) long are rarely weeviled; leaders longer than 23 inches (58.4 cm) are often weeviled (Silver 1968).

Trees become susceptible to weevil attack when they are 5 to 10 years old (about 5 feet (1.5 m) tall). Some trees continue to be attacked until they are at least 100 years old.[3/] Attack frequency is usually low in areas close to the ocean, but 1 or 2 miles (1.6-3.2 km) inland, 30 to 50 percent of the dominant and codominant trees may be attacked each year. Many trees are attacked 7 or more times by the time they are 30 years old. Weeviling of this intensity reduces height growth on a 30-year-old tree about 30 percent and stem volume about 20 percent (see footnote 3).

Although Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) often grow as well as spruce in coastal areas, spruce is still considered the most valuable tree on many sites, particularly in stream bottoms where spruce grows well and brush problems are severe. Spruce is also desirable in locations where animal browsing is prevalent.

For these reasons, considerable research has been undertaken to find a solution to the weevil problem. One study program that started some 16 years ago was the planting of several exotic and hybrid spruce trees to compare their growth potential and weevil susceptibility with that of native Sitka spruce. This paper summarizes the current status of that study.

[2/] Smith and Sugden (1969) determined that *Pissodes sitchensis*, *P. strobi*, and *P. engelmanni* were cytogenetically indistinguishable and synonymized them under the name *P. strobi*. The U.S. National Museum subsequently concurred (Warner 1971).

[3/] R. L. Carlson. The effect of the Sitka spruce weevil on Sitka spruce. Unpublished Master's thesis, on file at University of Washington, Seattle, 1966.

Figure 1.--Damage to Sitka spruce by *Pissodes strobi*. *A*, Weevil larvae mine down the terminal shortly after bud burst and, in midsummer, form pupal cells under the bark at the end of the mines. *B*, New growth arising from attacked terminal dies and starts to droop when the mining larvae grow large enough to sever conductive tissue. *C*, Multiple tops often develop when laterals below the killed terminal assume dominance. *D*, Killed terminals overgrown by laterals-turned-to-leaders result in poor stem form and decreased wood quality.

STUDY DESIGN AND METHODS

The study began in 1958 with the planting of 10 spruce species and hybrids in 3 plots near the coastal town of Raymond, Washington. One plot was located in a swampy site (called the Brooklyn plot), and another was located on a gentle, northwest-facing slope overlooking the town of Raymond (called the Raymond plot). The third plot, located in a stream bottom, was eventually abandoned because of severe damage by beavers. In 1961, a fourth plot, identical in design to the others, was established on a moderately steep, northeast-facing slope in the Cascade Head Experimental Forest near Otis, Oregon. One hundred trees--10 trees from each species or hybrid--were randomly selected for 10-foot spacing on each plot. Trees for these tests were made available by Dr. J. W. Duffield, then in charge of the Colonel W. B. Greeley Industrial Forestry Association Nursery at Nisqually, Washington.[4/]

Except for 4 years when the Cascade Head plot was not examined (1964-67), plots were evaluated annually for weeviling and for height growth of the trees. Data presented in this paper were collected through the 1972 growth season for the Washington plots and through the 1973 season for the Cascade Head plot.

[4/] Other individuals and organizations contributed at various times in the study: Mr. J. G. Wheat, who followed Dr. Duffield as Director of Research, Industrial Forestry Association; the Washington State Department of Natural Resources; and Werner Mayr Logging Company.

STUDY RESULTS

The significant findings of the study are summarized in table 1. General observations concerning the 10 species and hybrids are discussed below.

1. *Picea sitchensis* (native Sitka spruce). This species is the standard against which all other trees were compared. It was 1 of the 3 fastest growing trees on the plots but was weeviled a total of 65 times during the study period. Only 6 of the 30 study trees escaped attack. Most weeviled trees had poor form with multiple tops. Naturally regenerated Sitka spruce adjacent to the plots appeared to grow as rapidly and be weeviled as severely as those on the plots, indicating there was nothing unusual about the planting stock used in this study.

2. *Picea abies* (L.) Karst. (Norway spruce). This European species grew rapidly on all 3 plots but was also very susceptible to weeviling, showing 52 successful attacks on 30 study trees. Eight trees escaped weeviling. Trees were about twice as susceptible as Sitka spruce on the swampy Brooklyn plot but less susceptible on the other two plots (table 1). Trees that developed five or more terminals were quite common; often two or three terminals were weeviled in 1 year.

3. *Picea* X *lutzii* Little (Lutz spruce). This was the most promising hybrid (or species) in our test. Source of the planting stock was Alaska, where Sitka spruce and white spruce (*P. glauca* (Moench) Voss) mix and hybridize naturally (Little 1953). Growth approximated that of Sitka spruce, but only 6 weevilings were recorded on 30 trees. One tree was weeviled two times. Many more trees were attacked but unsuccessfully, apparently affected by a process of

Table 1.--Growth and weevil history of 10 spruce species or hybrids on 3 study plots

Species or hybrid	Number of surviving trees	Mean height of trees	Mean annual growth rate last 5 years	Total trees weeviled [1/]	Weevil index [2/]
		----------*Feet*----------			
RAYMOND PLOT					
Picea sitchensis	10	17.5	1.5	38	38.0
P. abies	10	18.8	1.5	22	22.0
P. X lutzii	10	17.0	1.7	3	3.0
P. mariana	9	13.3	1.2	0	0
P. sitchensis X glauca X glauca	8	13.2	1.3	0	0
P. glauca	10	12.0	1.2	0	0
P. engelmannii	9	10.6	1.2	0	0
P. engelmannii X glauca	8	7.0	.9	0	0
P. jezoensis	4	2.9	.3	0	0
P. glehnii	5	1.9	.2	0	0
BROOKLYN PLOT					
P. sitchensis	10	12.4	1.1	12	12.0
P. abies	10	13.8	1.3	24	24.0
P. X lutzii	10	11.4	1.0	0	0
P. mariana	10	13.1	1.1	2	2.0
P. sitchensis X glauca X glauca	10	9.2	.8	0	0
P. glauca	10	7.4	.7	0	0
P. engelmannii	10	7.6	.8	1	1.0
P. engelmannii X glauca	6	3.1	.3	0	0
P. jezoensis	4	2.1	.3	0	0
P. glehnii	5	1.2	.1	0	0
CASCADE HEAD PLOT					
P. sitchensis	10	17.8	1.6	15	15.0
P. abies	10	15.8	1.6	6	6.0
P. X lutzii	10	19.8	1.8	3	3.0
P. mariana	10	9.2	.9	1	1.0
P. sitchensis X glauca X glauca	8	10.2	1.0	0	0
P. glauca	10	10.1	.8	2	2.0
P. engelmannii	10	15.1	1.2	0	0
P. engelmannii X glauca	10	6.6	.6	0	0
P. jezoensis	7	2.6	.2	0	0
P. glehnii	0	--	--	--	--
ALL PLOTS					
P. sitchensis	30	15.9	1.4	65	22.0
P. abies	30	16.1	1.5	52	17.0
P. X lutzii	30	16.1	1.5	6	2.0
P. mariana	29	11.8	1.1	3	1.0
P. sitchensis X glauca X glauca	26	10.7	1.1	0	0
P. glauca	30	9.8	.9	2	.7
P. engelmannii	29	8.5	1.0	1	.3
P. engelmannii X glauca	24	5.9	.6	0	0
P. jezoensis	15	2.6	.3	0	0
P. glehnii	10	1.5	.2	0	0

[1/] The number of successful weevil attacks were recorded each year; some trees were weeviled several times during the period of study.

[2/] Total trees weeviled times 10, divided by the number of trees exposed to weeviling.

antibiosis--i.e., eggs appeared to be killed by resin before they could hatch. A degree of nonpreference, i.e., avoidance of the tree, may also be operating with Lutz spruce since the combined total of aborted and successful attacks was less than on Sitka spruce.

4. *Picea mariana* (Mill.) B.S.P. (black spruce). This is the common black spruce that ranges across northern North America from Newfoundland to Alaska. It had relatively good growth rate on the swampy plot but grew poorly on the other two plots. Three weevilings were recorded on 29 trees. Slow growth probably kept weeviling low; but because some of the trees grew rather well, it is possible that black spruce has some natural resistance to weevil attack.

5. *Picea sitchensis* X *glauca* X *glauca*. This is a horticultural hybrid of Sitka spruce and white spruce with a backcross to white spruce. The 26 surviving trees were attacked several times by the weevil; but all attacks were aborted by heavy pitching, indicating natural resistance to weevil attack. But, because only a few trees grew fast enough to be considered susceptible to attack, it is unknown whether the absence of weeviling was due solely to inherent resistance.

6. *Picea glauca* (white spruce). This is the common white spruce of northern North America, extending across the continent from the Atlantic Ocean to Alaska. Except on the swampy plot, growth was about the same as for the Sitka-white spruce backcross mentioned above. Many aborted weevil attacks were observed, but only 2 were successful on 30 trees. Again, the low attack rate could reflect slow growth, inherent resistance, or both.

7. *Picea engelmannii* Parry (Engelmann spruce). This tree is found at high elevations throughout much of Western North America. Growth on the two Washington plots was rather poor but quite good at Cascade Head in Oregon. In its natural environment, the tree is commonly attacked by the formerly named *Pissodes engelmanni* Hopkins, now synonymized as *P. strobi*. One successful attack on 29 trees was recorded in this study. It is possible this tree has some inherent resistance to weevil attack but is obscured by generally slow growth.

8. *Picea engelmannii* X *glauca*. This is a horticultural cross of Engelmann and white spruce. Survival and growth were poor on all three plots. Only at Cascade Head did any trees reach 5 feet. Accordingly, this tree, as well as the next two, was really untested as to weevil susceptibility. No weeviling was noted on 24 surviving trees.

9. *Picea jezoensis* (Sieb. & Zucc.) Carr. This Japanese tree grew poorly with no trees reaching 5 feet in height. No weeviling was observed on 15 trees.

10. *Picea glehnii* (F. Schmidt) Mast. Survival and growth of this species, another Japanese spruce, were poor. No trees attained a height of 5 feet. No weeviling was observed on 10 trees.

CONCLUSIONS

Except for Lutz spruce, it appears that most of the hybrids and exotic species studied are unsuitable for planting in the coastal spruce-hemlock zone of the Pacific Northwest. Growth is too slow or susceptibility to weeviling too great. Although white spruce showed poor growth, an apparently innate resistance to weevil attack makes the tree attractive from the genetic point of view. When crossed with Sitka spruce, the progeny appear to have the best characteristics of both parents. *P.* X *lutzii*, the

natural Sitka-white spruce hybrid, grew about as well as Sitka spruce yet suffered only about 10 percent as much weeviling. It is too early to know if inherent resistance is present, but Engelmann and black spruce may also be candidates for crossing experiments.

We feel enough promise is shown by *P.* X *lutzii*, from the standpoint of growth and weevil resistance, to encourage further experimental plantings of this hybrid. Such action could answer several important questions, for example, the most desirable seed sources. The exact source of the *P.* X *lutzii* used in this study is unknown, other than it came from Alaska. Presumably, nature has provided many crosses and backcrosses between Sitka and white spruce where the species merge in Canada and Alaska. There must be a continuum extending from trees that, genetically, are mostly Sitka spruce to trees that are mostly white spruce. Since trees along this continuum likely have different growth and weevil susceptibility characteristics, there should be an attempt to find out what seed sources are best for planting in Oregon and Washington.

Rather sizable test plantations of *P.* X *lutzii* would be desirable. In the plots described in this study, the weevils had an equal opportunity to attack any spruce. It is possible that if Lutz spruce were to be widely planted on an operational basis, the weevil might attack it in the absence of more susceptible species.

Trees in the three study plots will continue to be observed for several more years to see if there is a change in either growth habits or susceptibility to weeviling. In addition, Sitka spruce seedlings from three seed sources in Alaska--where weevil damage has never been found--have also been planted on two of the plots. The aim here is to determine if the weevil is absent in Alaska because of some inherent characteristics of the local trees.

We also anticipate that a genetic breeding program will eventually evolve for developing better trees in terms of growth and weevil resistance. Because attempts to find weevil-resistant individuals in the natural Sitka spruce population have been unproductive, such a program would likely utilize the gene pool of Lutz and white spruce. Because progeny testing for weevil resistance requires a minimum of 15 years, such a program should be started as soon as possible.

LITERATURE CITED

Gara, R. I., R. L. Carlson, and B. F. Hrutfiord
1971. Influence of some physical and host factors on the behavior of the Sitka spruce weevil, *Pissodes sitchensis* in southwestern Washington. Ann. Entomol. Soc. Am. 64: 467-471.

Johnson, Norman E.
1965. Distribution of Sitka spruce weevil eggs on leaders of open-grown spruce in southwest Washington. Weyerhaeuser For. Pap. No. 3, 11 p., illus.

Little, Elbert L., Jr.
1953. A natural hybrid spruce in Alaska. J. For. 51: 745-747.

McMullen, L. H., and S. F. Condrashoff
1973. Notes on dispersal, longevity, and overwintering of adult *Pissodes strobi* (Peck) (Coleoptera: Curculionidae) on Vancouver Island. J. Entomol. Soc. B.C. 70: 22-26.

Ruth, Robert H.
1958. Silvical characteristics of Sitka spruce. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn. Silvical Ser. No. 8, 19 p., illus.

Silver, G. T.
1968. Studies on the Sitka spruce weevil, *Pissodes sitchensis*, in British Columbia. Can. Entomol. 100: 93-110, illus.

Smith, S. G., and B. A. Sugden
1969. Host trees and breeding sites of native North American *Pissodes* bark weevils, with a note on synonymy. Ann. Entomol. Soc. Am. 62(1): 146-148.

Warner, Rose Ella
1971. Synonymy in the genus *Pissodes* (Coleoptera: Curculionidae). U.S. Dep. Agric. Coop. Econ. Insect Rep. 21(9): 106.

Wright, Kenneth H.
1960. Sitka-spruce weevil. U.S. Dep. Agric. For. Pest Leafl. 47 (rev.), 6 p., illus.

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PACIFIC NORTH WEST
FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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May 1974

EFFECT ON DIAMETER ESTIMATES OF ROUNDING RULES IN SCALING

by

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and

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ABSTRACT

Treatment of diameter measurements in Pacific Northwest scaling practice results in lower recorded diameters than those obtained by measuring to the nearest one-tenth inch. This would bias cubic volume estimates unless appropriately adjusted.

Keywords: Log scaling, measurement systems.

INTRODUCTION

Recently, two Scaling Bureaus have agreed to scale logs with two end-diameter measurements on special request. These measurements should make possible accurate estimates of the cubic-foot volume of the scaled logs. However, two current board-foot scaling practices will bias these estimates.

On the west side of the Cascade Range the scaling practice is to drop fractional inches and use the next lower full inch of diameter. Out-of-round logs have both the long diameter and the short diameter measured this way. The recorded diameter is the average of two measurements taken to the next lower inch. If this average is not a whole number, the fraction is dropped before recording.

On the east side, diameters are scaled to the nearest inch. However, again, two such measurements--long and short diameters--are averaged before recording. If there is a fraction, it is always a half-inch and it is dropped before recording.

These scaling procedures suggest many questions:

1. How much bias is caused by scaling to the next lower inch?
2. Is any bias caused by scaling to the nearest inch?
3. How much bias is caused by dropping half-inches before recording the average of the long and short diameters?
4. How many logs must be measured before variation around expected biases is reduced to about 0.05 inch?
5. How much effect do these biases have on volume estimates? All these questions, except the third, can be answered by use of mathematical theory.

Since mathematical theory is more convincing to some when it has a simple demonstration in observed results, we looked for suitable field records. We found scaling records of nearly 3,000 logs cut from over 700 Douglas-fir trees in mill recovery studies performed by the Station's Timber Quality Project. This includes both old-growth and young-growth trees; but more importantly, it includes logs whose scaling diameters were measured to the nearest one-tenth inch.

These records were used to compare west-side and east-side scaling practices with the possibly more accurate practice of measuring diameters to the nearest one-tenth inch and retaining the fraction when averaging long and short diameters. It is recognized that no attempt should be made in practical work to measure this closely large logs with irregularly shaped ends. However, such records can be used to detect the biases in which we were interested.

Consideration of the theoretical aspects of the problem suggested we should include in our comparisons modifications of the west-side and east-side rules. These were to record the half-inch when rounded long and short diameters were averaged. The modified east-side rule, measuring to the nearest inch and retaining the half-inch in the average when it occurred, should have no bias when compared with measurements to the nearest one-tenth inch on a large enough number of logs. The alternative possibility of always rounding the average diameter to the nearest even number of inches was not tested because it would increase variability. (There would be about three times as many logs assigned even-inch diameters as odd-inch.)

The reader not interested in technical stuff and theoretical outcomes can skip to the results section.

TECHNICAL STUFF

Both west-side and east-side scale sticks have marks dividing them into 1-inch intervals. On west-side sticks, these intervals are marked at points a full number of inches from the zero end of the stick. On east-side sticks they are offset to the half-inch points. A west-side scale stick assigns a 12-inch diameter to logs whose diameter inside bark falls between the marks at 12.0 and 13.0 inches. An east-side stick does the same for diameters between 11.5 and 12.5 inches. It is easy to see that the difference in graduations on the west-side and east-side rules makes the exact average of a large number of west-side measurements a half-inch smaller than the average of the east-side measurements on the same logs.

When the logs were measured to the nearest one-tenth inch, a scale graduated in inches and tenths was used. A measurement was assigned to the log by placing the 0 division on one side and reading the rule to the tenth inch nearest the other side of the log. Thus any diameter that fell within 0.05 inch of the tenth-inch mark was assigned the tenth-inch value.

Converting these measurements to west-side and east-side measurements is complicated whenever a tenth-inch diameter coincides with a graduation mark on the scale stick being tested. For west-side scaling this occurs at full inches and for east-side scaling, at half-inches. At these points, placement of the nearest tenth-inch measurements into the proper scaling diameter is impossible since it is unknown if the actual diameter was above or below the tenth-inch mark.

To circumvent this problem, a constant of 0.025 inch was added and subtracted from each tenth-inch diameter measurement recorded for a log. Since each log had two such diameter measurements, four addition-subtraction combinations had to be calculated. Scaling diameters were assigned to each combination and then each rule was tested as now used and as modified to retain the half-inch when averaging the long and short diameters.

THEORETICAL OUTCOMES

As already stated, a half-inch difference was expected between the average of west-side and east-side measurements. Also, it was hypothesized that there would be somewhat less than a quarter-inch difference between each modified rule and its unmodified form for small logs. This was based on the notion that small logs are less out-of-round than large logs and that therefore fewer than half of the average diameters would involve one odd number and one even number. With large logs, a wider range of out-of-roundness would give an expected ratio of one-half the averages being based on one odd and one even diameter, and there should be a quarter-inch bias.

A small amount of arithmetic is needed to calculate theoretically how many logs must be measured to reduce variation to any desired level between mean diameters of logs based on one-tenth-inch measurements and on measurement by 1-inch classes. Take a 1-inch class and divide it into 10 parts. Calculate the deviations of the centers of these 10 classes from the middle of the inch class. The root mean square of these

deviations (0.287 inch) can be taken as an estimate of the standard deviation of a large number of such measurements.

Thus, if 100 logs were put into a single inch class by 1 measurement per log to the nearest inch, the mean of the 100 measurements to the nearest one-tenth inch would have a standard error of 0.0287 inch. Thus, 1 mean value out of 20 such means can be expected to deviate more than 0.0574 inch from the midclass value. The example we deal with is slightly more complicated because our basic record is the average of two diameter measurements.

The theoretical effect on volume estimation of a negative bias in diameter records is easy to work out. Let $V = aD^2L$ for volume of a log based on its average diameter and length. A biased diameter record gives a biased volume estimate $V_B = a(D-B)^2L$. It follows that:

$$\begin{aligned} V_B/V &= (a[D-B]^2L)/(aD^2L) \\ &= (D-B)^2/D^2 \\ &= (D^2 - 2DB + B^2)/D^2 \\ &= 1-2B/D + B^2/D^2 \end{aligned}$$

where B^2/D^2 is negligible and the loss in volume expressed as a ratio is about $2B/D$. Thus, a half-inch bias in a 10-inch log biases the volume estimate downward by about 10 percent.

RESULTS

As expected, scaling to the next lower inch (west side) caused the recorded diameters to be about one-half inch lower than scaling to the nearest inch (east side) (table 1, figs. 1 and 2). There was no apparent bias in the modified east-side rule. (The modification was to record any half-inch calculated when averaging the long and short diameters.)

The bias caused by dropping fractional inches when averaging long and short diameters appears to be about 0.20 inch for logs under 10 inches and 0.25 inch for logs over 10 inches.

It takes a large number of logs in each diameter class to reduce variations between mean values estimated from measurements made to different limits of accuracy. However, none of the observed deviations appear to be greater than two standard deviations calculated as suggested in the theoretical section.

Finally the volume biases shown in figure 3 are just about what was expected. These volume biases clearly indicate that some adjustment must be made before calculating cubic volumes from diameters recorded by board-foot scaling practices. Either the east-side practice modified by recording half-inches when averaging should be used or an appropriate amount added to the recorded diameter. In west-side practice this appears to be 0.70 inch for logs under 10 inches and 0.75 inch for logs over 10 inches. In east-side practice, the amounts added would be 0.20 inch for small logs and 0.25 inch for large.

Table 1.--*Biases of average diameters based on four scaling practices expressed as differences from diameters measured to the nearest one-tenth inch and averaged*

Diameter class (inches)	Approximate number of logs	Average diameter measured to one-tenth inch	Biases			
			East-side modified	East side	West-side modified	West side
			Inches			
5.01-10.00	359	8.09	0	-0.21	-0.51	-0.69
10.01-15.00	596	12.56	0	-.26	-.49	-.74
15.01-20.00	557	17.44	+.01	-.26	-.49	-.76
20.01-25.00	469	22.39	+.01	-.27	-.49	-.74
25.01-30.00	372	27.38	-.01	-.27	-.48	-.74
30.01-35.00	270	32.39	0	-.26	-.50	-.75
35.01-40.00	186	37.38	+.01	-.26	-.51	-.77
40.01-45.00	94	42.23	+.02	-.23	-.49	-.74
45.01-64.50	74	49.81	+.01	-.25	-.47	-.73
Sums and means	2,976	21.542	+.001	-.259	-.495	-.744

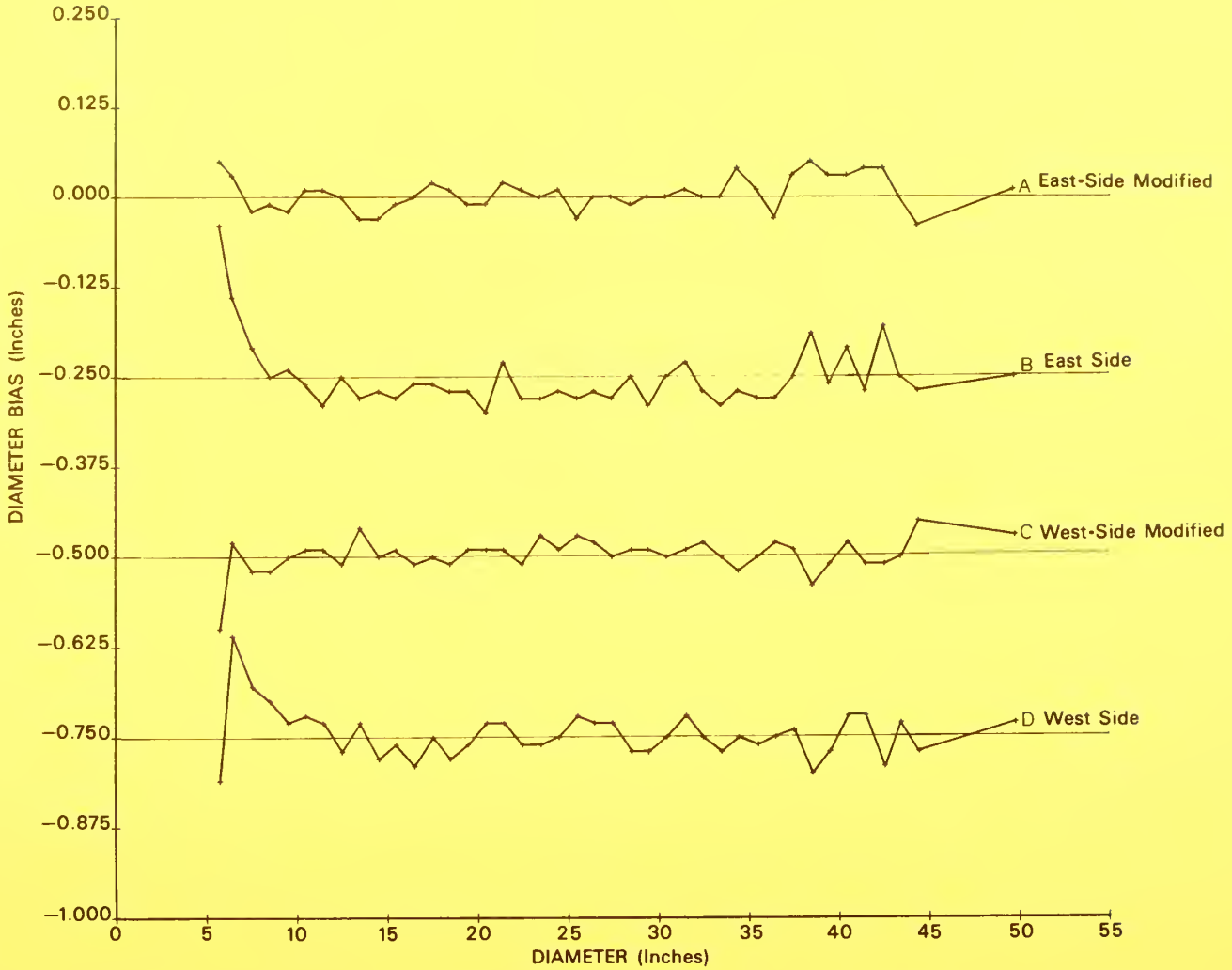

Figure 1.--Average diameter bias when using east-side modified, east-side, west-side modified, and west-side scaling rules. Based on 1-inch diameter classes starting at 5.01 inches.

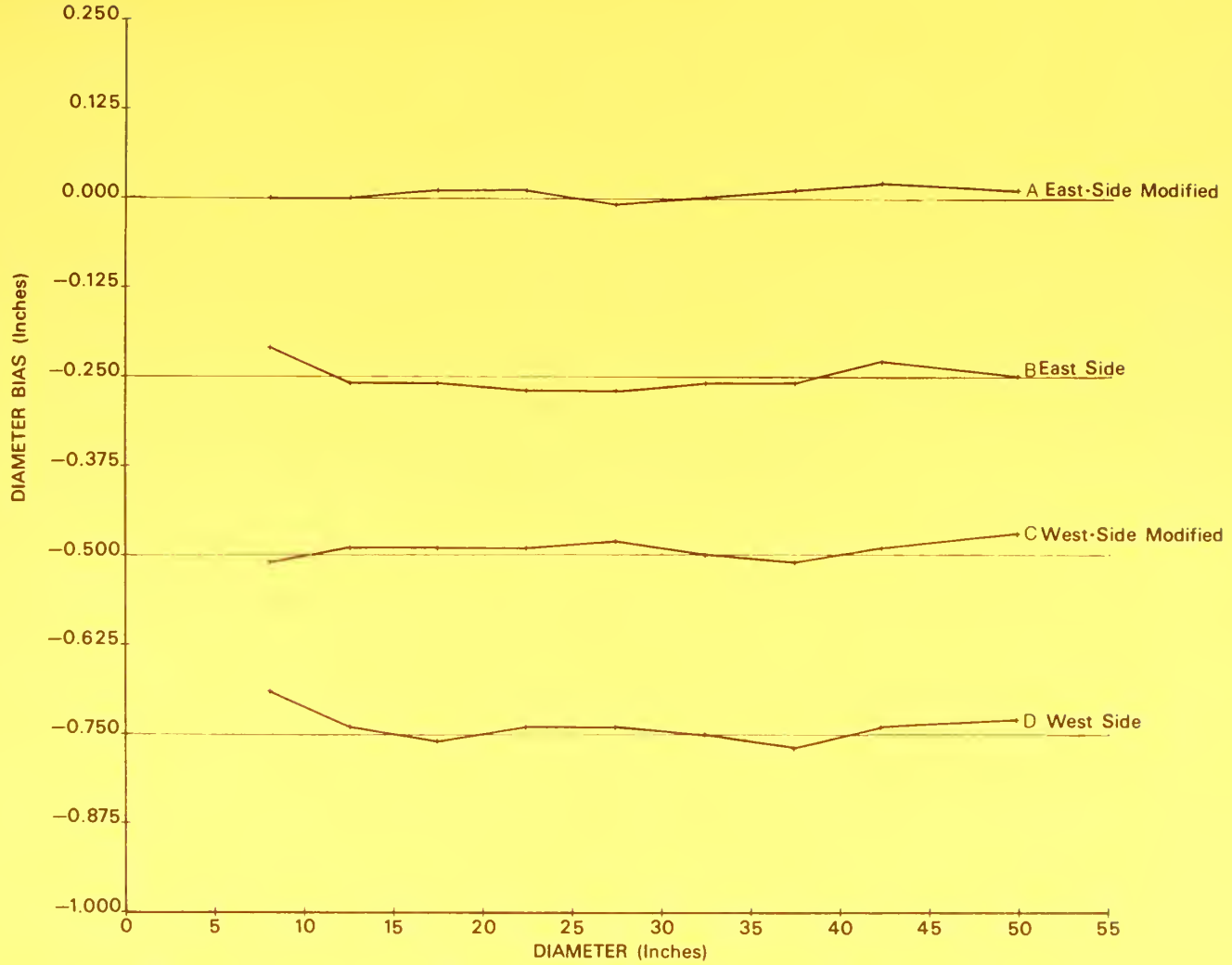

Figure 2.--Average diameter bias when using east-side modified, east-side, west-side modified, and west-side scaling rules. Based on 5-inch diameter classes starting at 5.01 inches.

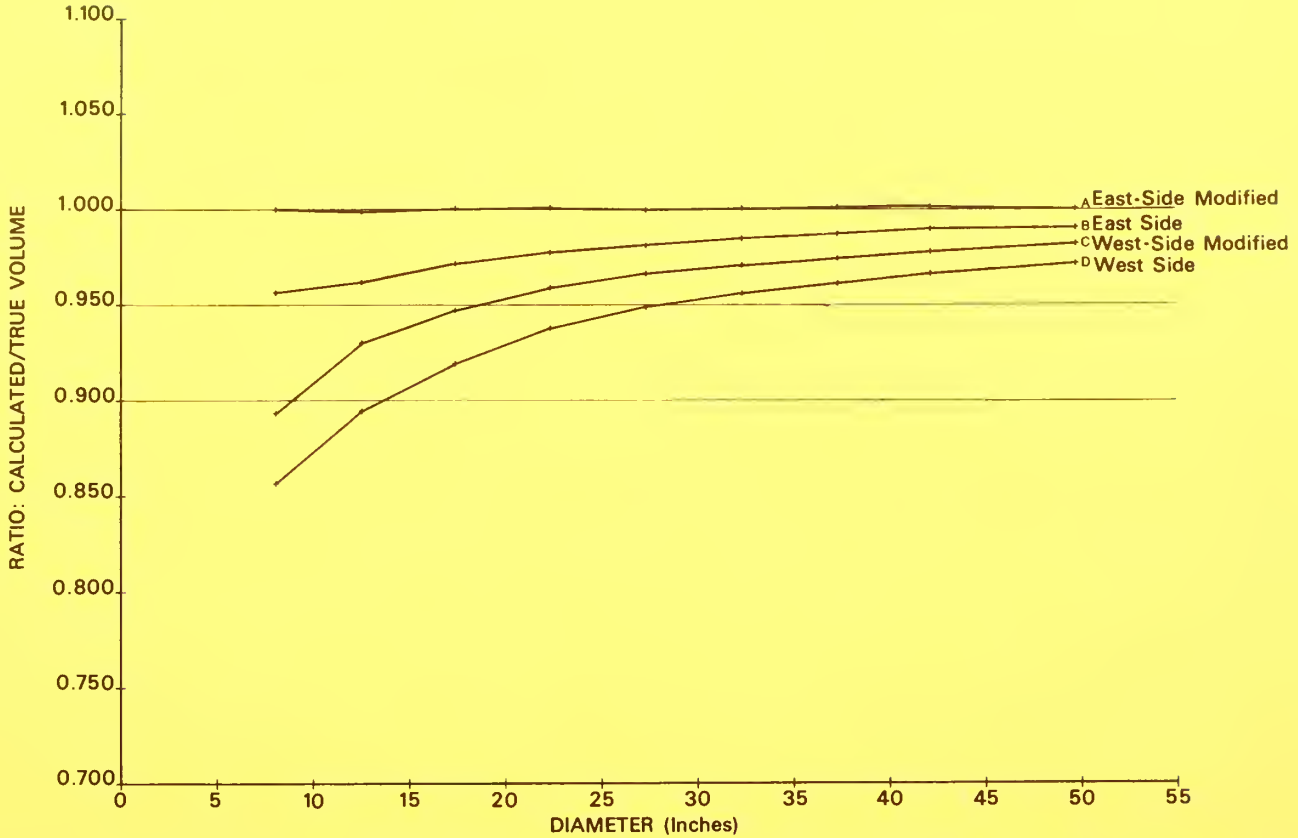

Figure 3.--Ratios of estimated volumes using four scaling rules to estimated volumes using 1/10-inch diameter measurements. Based on 5-inch diameter classes starting at 5.01 inches.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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DOUGLAS-FIR THINNING VALUES SENSITIVE TO PRICE-DIAMETER RELATIONSHIPS

by

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and

David R. Darr, *Economist*

ABSTRACT

This paper examines the impact of four alternative price-diameter relationships on the present net worths obtained from an evaluation of commercial and precommercial thinning in Douglas-fir stands varying by age and site class. Of special interest was how different relationships affected the magnitudes of projected returns and how rankings were affected. It was found that alternative assumptions could produce large differences in present net worth values in some cases, changing the financial desirability of thinning among stands of Douglas-fir. Analysis showed that large differences persisted over a wide range of interest rates.

Keywords: Stumpage prices, stand development, stand diameter (mean), thinning -) economic evaluation.

EST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

BACKGROUND

If an analyst attempts to project returns expected from managing a stand of timber, one of his tasks is to select stumpage prices for evaluation of intermediate and final harvests. Because these harvest yields occur at different stages of stand development, they represent various average tree diameter situations. The analyst must identify or assume a relationship between stumpage price and stand diameter.

In previous studies, when a price-diameter relationship has been considered in investment analysis, generally only one relationship has been used and the potential sensitivity of study results to stumpage price variation has not been fully examined. For example, Teeguarden[1/] calculated stumpage prices for stands averaging 10-inch d.b.h. at one-half the assumed price for a 19-inch d.b.h. and then assumed that prices for intermediate diameters would follow a linear relationship. In the "Douglas-fir Supply Study,"[2/] analyses were based on the assumption that prices for thinnings, salvage of dead trees, and smaller trees removed in prelogging equaled 75 percent of final harvest prices. Exceptions were Lundgren,[3/] Rose,[4/] and Chambers and Pierson,[5/] who examined some investment effects of alternative price-diameter relationships.

This paper shows how present net worth values, derived for the financial evaluation of commercial and precommercial thinning opportunities in Douglas-fir, can be influenced by any one of four alternative assumptions about price-diameter relationships. The paper also shows how these assumptions can influence expected returns and decisions associated with thinning Douglas-fir.

[1/] Dennis E. Teeguarden. Economics of replacing young-growth ponderosa pine stands...a case study. USDA Forest Service Research Paper PSW-47, 16 p. Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., 1968.

[2/] USDA Forest Service. Douglas-fir supply study. 53 p., illus. USDA Forest Service, Regions 5 and 6 and Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1969.

[3/] Allen L. Lundgren. Thinning red pine for high investment returns. USDA Forest Service Research Paper LS-18, 20 p., illus. Lake States Forest Experiment Station, St. Paul, Minn., 1965.

[4/] Dietmar W. Rose. Stumpage dimensions and stumpage value. The Forestry Chronicle 49: 226-227, 1973.

[5/] Charles J. Chambers and Richard N. Pierson. Does commercial thinning pay under sustainable harvest? Oregon State University. Short course on management of young Douglas-fir and western hemlock, June 13, 1973. Proceedings in press.

FRAMEWORK FOR ANALYSIS

Evaluations of the contribution to present net worth of commercial and precommercial thinning in several Douglas-fir stands varying by age and site class provided the basis for testing four assumed price-diameter relationships.[6/] The four price-diameter relationships tested are as follows:

1. The average value per thousand board feet, Scribner scale, for all stumpage harvested in thinning operations equals 75 percent of the average value of final harvest stumpage of $30 per thousand board feet (based on 1970-71 prices).

2. The average value of stumpage from thinnings equals the average value of stumpage from final harvest operations and is equal to $30 per thousand board feet.

3. The average value of 8-inch-d.b.h. trees is equal to 75 percent of the average value of trees 20 inches and over, and the stumpage increases in value proportionate to increases in diameter breast high up to 20 inches which has an average value of $30 per thousand board feet.

4. Stumpage price is equal to a function of the logarithm of average stand diameter.

$$P = a + b \log (D)$$

where

P = stumpage price

a and b are constants

D = average stand diameter

We used these assumptions to derive four sets of present net worth values which were then analyzed to determine what effects, if any, varying assumptions might have on the values and the decisions based on them. Because local market conditions vary and can change over time, our list of price-diameter relationships is by no means exhaustive. The validity of any one of our four or other possible relationships will depend on local market conditions, which can change over time. For example, adoption of small log technology by mills in an area may increase the value of small-diameter timber relative to larger timber.

[6/] Additional details concerning the procedures and data base used in calculating present net worth of commercial and precommercial thinning in Douglas-fir are contained in an office report and may be obtained upon request from the authors.

RESULTS

Figure 1 shows the contribution to present net worth of commercial thinning in Douglas-fir stands classified by site class and stand age. Four assumptions are shown for each age-site combination. The numbers correspond to the numbered assumptions outlined in the preceding section. For any assumption, the relative benefits of thinning in stands varying by age and site class can be determined and compared. For example, using assumption 2, one can determine that thinning begun in a site I stand at age 50 is valued at $406 and thinning begun in a 30-year-old stand on the same site is valued at $258. Managers could use such information, with information on budget and manpower ceilings and limitations on cutting of volume and acreage, to derive rankings which could be used to determine the order of cutting.

Figure 1 also shows that different assumptions about the price-diameter relationship can influence the relative ordinal ranking of stands based on the level of present net worth. For example, assumption 1 gives a higher value for a 45-year-old site II stand than it does to a 55-year-old site II stand. Assumptions 2, 3, and 4, however, give the 55-year-old stand a higher value.

Figure 1 can also be used to derive the difference in present net worth between the assumption producing the highest value and the assumption producing the lowest value for each site-class, stand-age combination. Thus, figure 1 also gives a measure of the magnitude of differences in present net worth values that can result from changing assumptions. For example, the 45-year-old site II stand has over four times the value with assumption 2 than when assumption 4 is used. If for planning purposes, management wants reasonably close estimates of cash flows from commercial thinning, then the assumption used can make a substantial difference. Figure 2 shows that varying interest rates do not change the results shown in figure 1. We use as an example the same site-II, age-45 stand described above. The values generated by the different assumptions tend to maintain their position even though interest rate varies from 3 to 10 percent.

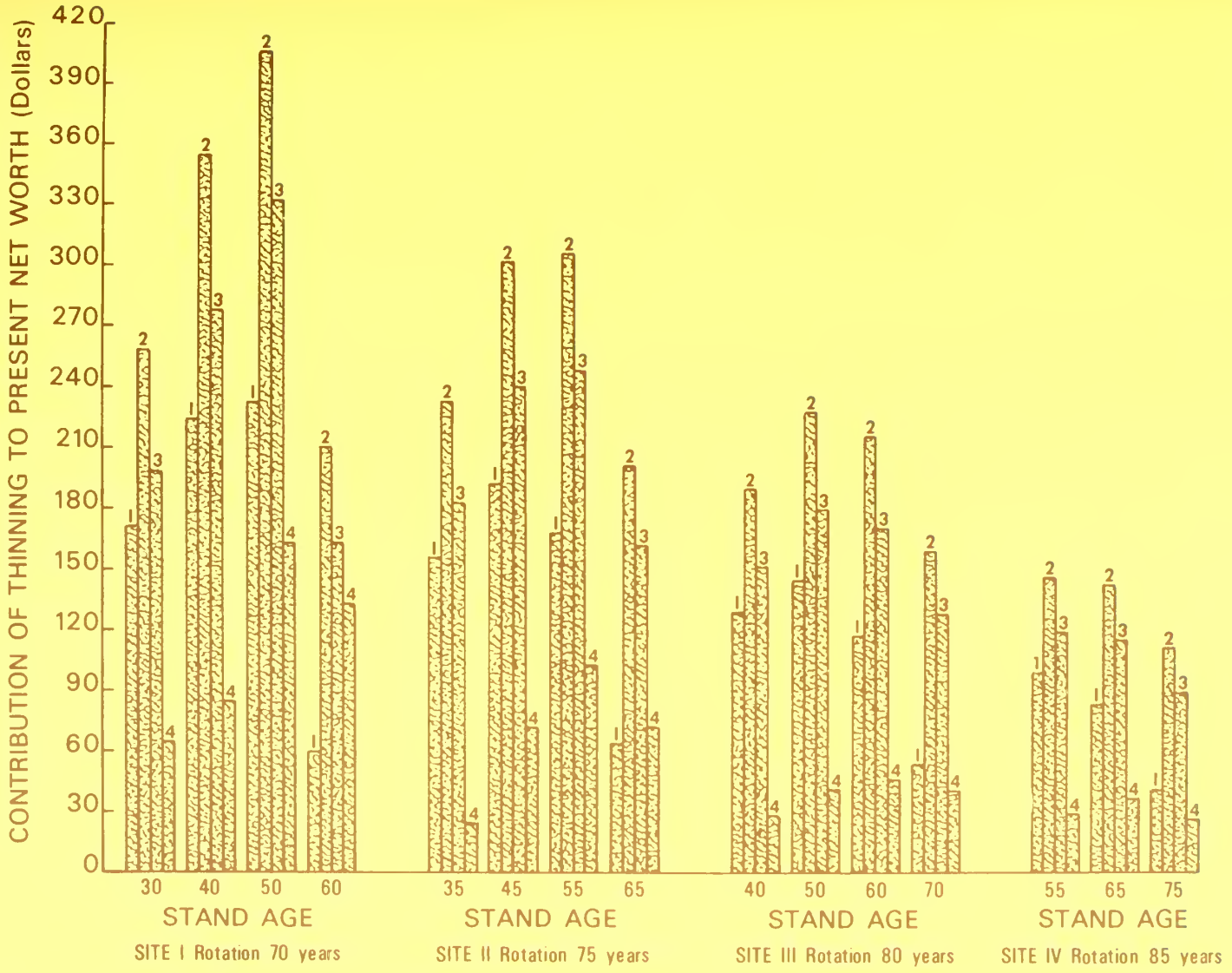

Figure 1.--Comparison of contribution to present net worth of commercial thinning in Douglas-fir stands varying by age and site class under each of four assumptions about price-diameter relationships. Discount rate is 5 percent.

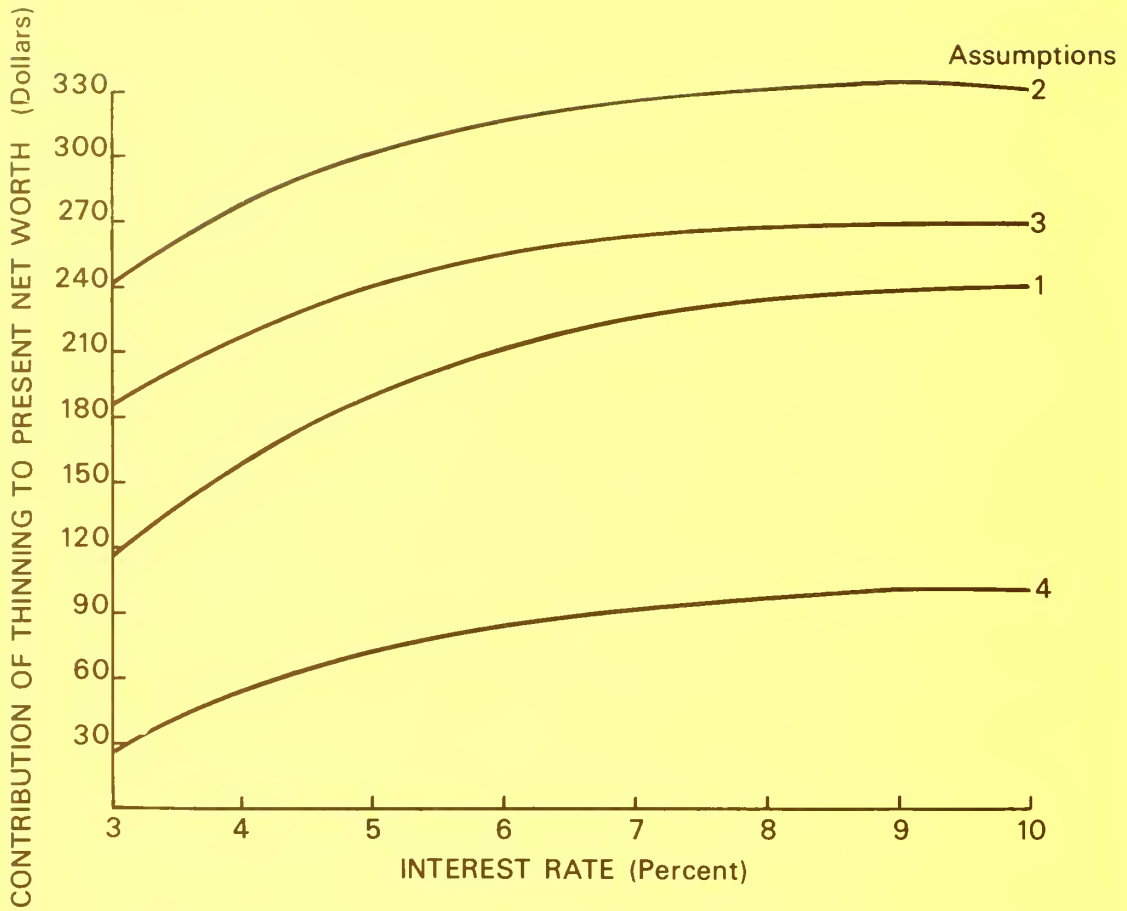

Figure 2.--Comparison of contribution to present net worth of commercial thinning in an age-45, site-II Douglas-fir stand under four assumptions about price-diameter relationships and under varying interest rates. Rotation age is 75 years.

The price-diameter relationship assumed can be especially crucial to the decision of whether to precommercially thin or not. Unlike commercial thinning where costs are recovered in the current operation, precommercial thinning involves an investment with returns deferred to some future time. To illustrate, assume precommercial thinning costs are $60 per acre and table 1 represents the discounted net returns from future harvests. To decide whether or not to thin, we need to compare the $60-investment cost with the entries in the table. If the discounted net return is more than $60, we would undertake the investment; if it is less, we would not. For site I, note that all assumptions would allow the investment but for site III, none of the assumptions would allow it. With site II, however, the decision depends upon the assumption made. Assumptions 2 and 3 show benefits exceeding the cost, but assumptions 1 and 4 show the cost to exceed discounted returns.

Table 1.--*Net returns in dollars per acre from harvests expected after precommercial thinning at age 15 in Douglas-fir. Net returns discounted to the present at 7 percent*

Site	Assumptions[1/]			
	1	2	3	4
	Dollars			
I	65	88	80	65
II	53	71	64	54
III	36	48	43	34

[1/] Assumptions: 1. The average value for all thinning stumpage equals 75 percent of the average value for final harvest stumpage. 2. The average value of thinning stumpage equals the average value for final harvest stumpage. 3. The average value of 8-inch-d.b.h. trees equals 75 percent of the average value of trees 20 inches and over. Stumpage between 8 and 20 inches increases in value proportionate to increase in diameter. 4. Stumpage price is equal to a function of the logarithm of average stand diameter.

In conclusion, this study demonstrates that care should be taken in selecting the price-diameter assumption used to evaluate forest management activities. The results show that not only can the assumption influence the priority of projects selected and the estimates of benefits expected, but that it can be decisive in influencing the project's financial feasibility.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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ATTAINMENT OF THE OVERWINTERING INSTAR AND THE CASEBEARING HABIT BY LARCH CASEBEARER LARVAE AT DIFFERENT ELEVATIONS IN THE BLUE MOUNTAINS

by

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DEC 7 1974
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ABSTRACT

The percentage of casebearing larvae on plots between 3,280- and 5,545-ft (1,000- and 1,690-m) elevation increased between September 11 and October 25 from 2.6 percent to 93 percent. Larvae at all elevations had reached the third (overwintering) instar by October 10. This information is useful in timing parasite releases or insecticide applications. Larvae at 4,000 ft (1,219 m) advanced more rapidly than larvae at higher or lower elevations.

Keywords: Larch casebearer, *Coleophora laricella*, insects, insect damage control (forest).

The larch casebearer, *Coleophora laricella* (Hbn.) (Lepidoptera: Coleophoridae), is spreading through the range of western larch, *Larix occidentalis* Nutt., and is causing increasingly severe defoliation, a pattern reminiscent of its history in eastern North America before it was brought under biological control. Attempts to achieve control of this insect in the West include recolonization of parasites from the East and new importations from Europe.[1/][2/] As a temporary measure, local suppression can be achieved by applications of insecticides against larvae during the spring feeding period.[3/]

For best results in any control effort, it is necessary to know the habits of the insect and its local phenology. In colonization of parasites, it is necessary to time releases in the best synchronization with susceptible host stages. Parasites of the casebearing stage, for example, such as *Chrysocharis laricinellae* (Ratz.), if released during the summer when nonsusceptible needle mining larvae were present, would have to await the shift from the mining to the casebearer habit before susceptible host larvae were available. Likewise, insecticide applications would probably be more effective after the assumption of the casebearing habit. Applications when larvae are mining needles would have to penetrate the needle cuticle to reach the larvae. Casebearing larvae, on the other hand, would be exposed to insecticide deposits on the surface of the needles as they changed feeding positions.

This study was undertaken to establish the time of occurrence of the shift from the mining to the casebearing habit by larch casebearer larvae as it occurs at different elevations in the Blue Mountains.

METHODS

Study areas were in the Blue Mountains of southeastern Washington, approximately 15 mi (25 km) south of Pomeroy. Plots consisted of larch of approximately 30 to 100 ft (10 to 30 m) in height mixed with varying proportions of *Abies grandis* (Dougl.) Lindl., *Pseudotsuga menziesii* (Mirb.) Franco, *Pinus contorta* Dougl., and *P. ponderosa* Laws. at elevations of 3,280 to 5,545 ft (1,000 to 1,690 m).

1/ Robert E. Denton. Establishment of *Agathis pumila* (Ratz.) for control of larch casebearer, and notes on native parasitism and predation in Idaho. USDA Forest Service Research Note INT-164, 6 p. Intermountain Forest and Range Experiment Station, Ogden, Utah, 1972.

2/ R. B. Ryan and R. E. Denton. Initial releases of *Chrysocharis laricinellae* and *Dicladocerus westwoodii* for biological control of the larch casebearer in the western United States. USDA Forest Service Research Note PNW-200, 4 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1973.

3/ Robert E. Denton and Scott Tunnock. Low-volume application of malathion by helicopter for controlling larch casebearer. Journal of Economic Entomology 61: 582-583, 1968.

Plots were located as follows:

	Elevation		Location
	ft	m	
Pataha Creek	3,280	(1,000)	T. 10 N., R. 42 E., sec. 15
Charley Creek	4,000	(1,219)	T. 9 N., R. 42 E., sec. 24
Road N94 at Martin Ridge	4,550	(1,387)	T. 9 N., R. 42 E., sec. 14
Road N94 at Big Spring Campground	5,000	(1,524)	T. 9 N., R. 42 E., sec. 27
Road N94 at snowmobile trail	5,545	(1,690)	T. 8 N., R. 42 E., sec. 4

Samples were taken at approximately 2-week intervals from September 11 to October 25, 1973. One branch approximately 12 in (30 cm) long was taken from the lower crown of each of two trees per plot. The branches were cut into short sections and placed in a plastic bag, which was then closed with a rubber band and identified by plot and date. Samples were either examined the same day or placed in a portable ice chest for transportation back to the laboratory and examined the next day. In the examination process, short sections of twig were removed from the sample bag at random and all larvae found were classified as to whether they were needle miners or casebearers. The former category included a few larvae found outside of the needles but which were not in cases, as these larvae would have reentered needles as miners.[4/]

Head capsule widths of all larvae on September 11, and 20 per plot on subsequent dates, were measured to determine instar until all found on any one date had transformed to the third, or overwintering, instar. The percentages of larvae reaching the overwintering instar and the percentages of larvae which had assumed the casebearing habit were computed separately for each elevation and date. These measurements were made at 60X magnification using a calibrated eyepiece micrometer of a dissecting microscope.

RESULTS AND DISCUSSION

Results are presented in figures 1 and 2. On September 11, 52 of 103, or 50.5 percent, of the larvae from all elevations measured for head capsule width had molted to the third instar. On September 26, 91 percent had reached the third instar, and by October 10, all had done so. Therefore, larvae in the final sample on October 25 were not measured for instar determination.

On September 11, only 7 of 265, or 2.6 percent, of larvae from all elevations had formed a case. On subsequent sampling dates of September 26, October 10, and October 25, the percentages of casebearers for all elevations rose to 18, 67, and 93, respectively.

[4/] Whether a larva is a needle miner or a casebearer has to do with its behavior. A larva is first a needle miner until it changes its habits and becomes a casebearer. This change occurs either late in the second instar (a morphological stage) or in the third instar. Thus, we have two measures of the developmental progress of a larva, one morphological and the other behavioral.

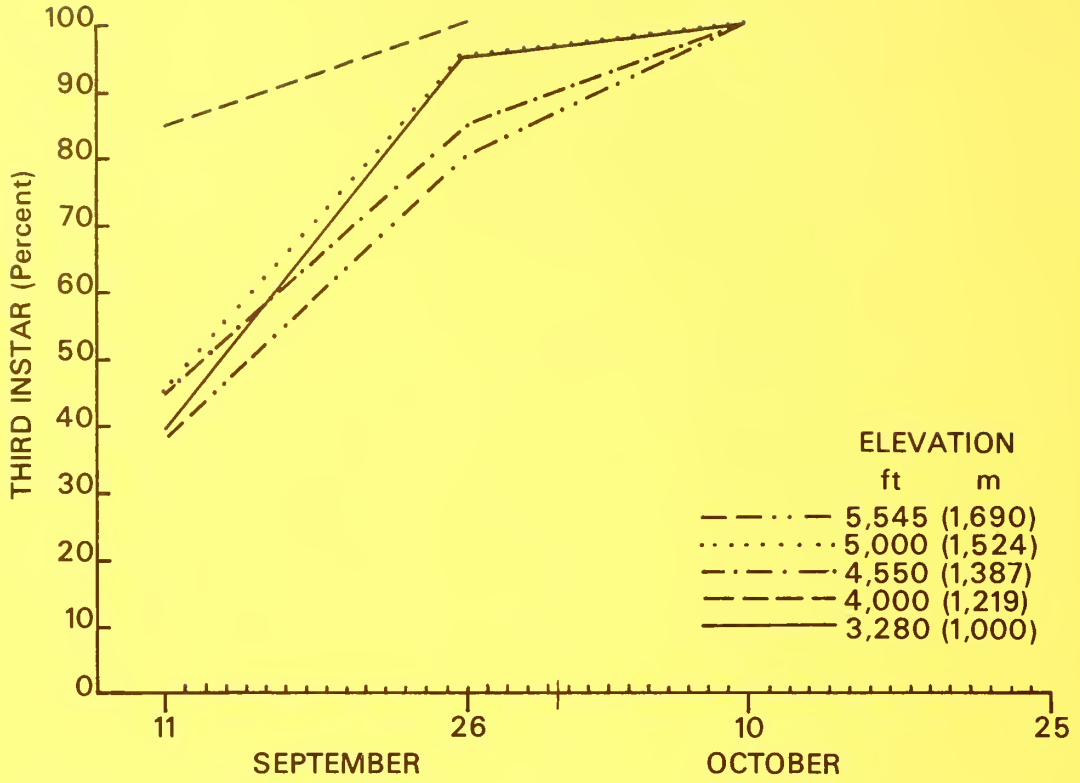

Figure 1.--Transformation to the third or overwintering instar by *Coleophora laricella* larvae at different elevations.

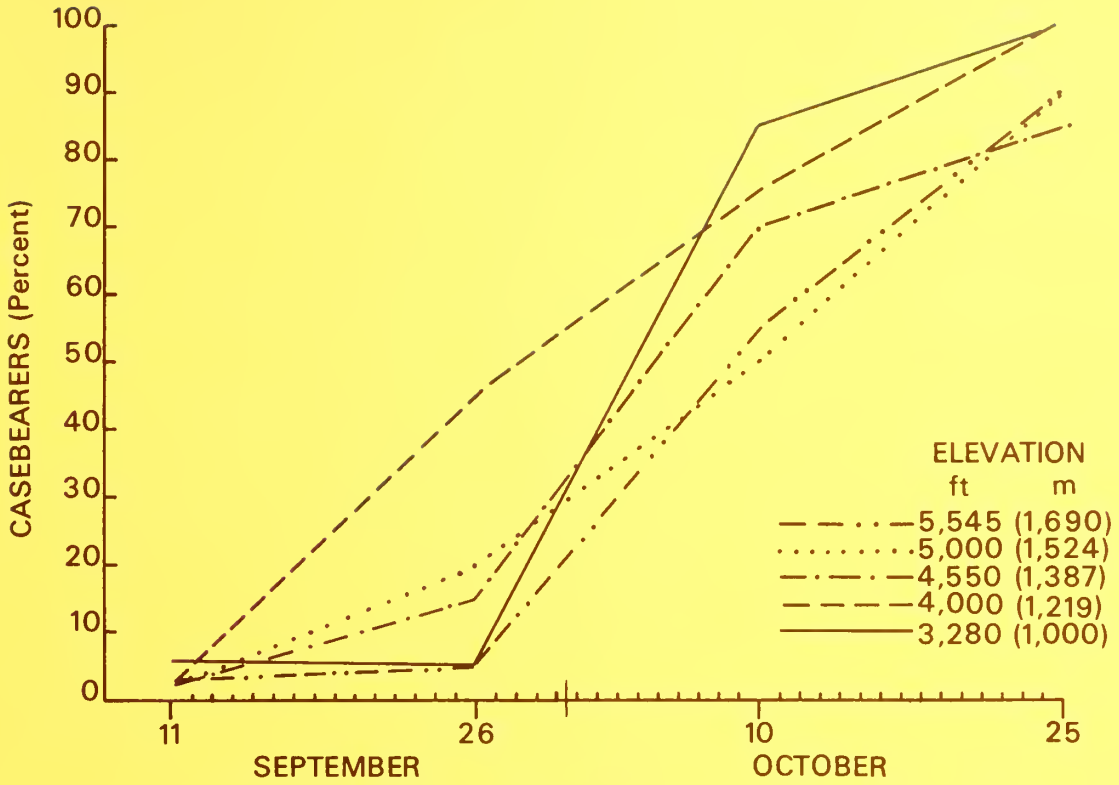

Figure 2.--Assumption of the casebearing habit by *Coleophora laricella* at different elevations.

As shown in figures 1 and 2, the population at the 4,000-ft (1,219-m) elevation was more advanced than populations at higher and lower elevations. This is evident from the higher percentage of third instars on September 11 and the higher percentage of casebearers on September 26. On September 26, larvae from 4,000-ft elevation were noticeably larger than larvae from 3,280 ft, even though essentially all were third instars. More rapid development at 4,000 ft than at higher elevations can possibly be attributed to temperature differences due to elevation. However, why the population at 4,000 ft should be more advanced than that at 3,280 ft is not completely clear, since both are creek-bottom plots with the same, essentially northerly, exposure.

Based on these 1973 data, parasite releases aimed at casebearing larvae should be delayed until mid-September, after which parasites would find some suitable hosts at all elevations. On the other hand, to find a fall date for insecticide treatment when all larvae were casebearers would be difficult. Some needle miners are present well into late October when the risk of inclement weather would make insecticide application, especially by aircraft, difficult.

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USDA FOREST SERVICE RESEARCH NOTE

9.7PNW-229

PNW-229

June 1974

NATURAL REPRODUCTION OF GRAND FIR AND MOUNTAIN HEMLOCK AFTER SHELTERWOOD CUTTING IN CENTRAL OREGON

by

K. W. Seidel and R. Cooley 1/

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ABSTRACT

The establishment and survival of grand fir and mountain hemlock seedlings in the Oregon Cascades were determined for a 2-year period following shelterwood cutting and a good seed crop. Mortality of both species was heavy; 71 percent of the fir and 90 percent of the hemlock seedlings initially established died. Number of seedlings per milacre was significantly correlated with amount of residual overstory; more seedlings of both species were established, and survival of grand fir was better, as stand density increased. Drought was not a mortality factor during the second summer, since seedling moisture stresses never became critical.

Keywords: Regeneration (natural), shelterwood cutting method, timber management planning.

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There has been a recent increase in demand for logs from the true fir-mountain hemlock forests of the Oregon Cascades. Despite the increased utilization of this timber resource, little is known about silvicultural systems best suited for obtaining natural regeneration. Until recently, primarily clearcutting was used to harvest true fir-mountain hemlock stands on National Forest lands. In some cases, natural regeneration of true fir has been adequate (Gratkowski 1958), but in many others little or no natural regeneration has occurred (Franklin 1965*a*, Franklin and Smith 1974).

Recognizing that shade-tolerant species found in the fir-hemlock type might regenerate better after partial cutting, the Deschutes National Forest began using the shelterwood method in 1971. This paper reports the natural regeneration of grand fir (*Abies grandis* (Dougl.) Lindl.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) following a good seed year in response to variations in density of the residual stand. [2/]

STUDY AREA AND METHODS

The study area is located in the Three Sisters Province, Oregon High Cascades (Franklin 1965*b*), about 30 miles (48.3 km) southwest of Bend, Oregon, in the Deschutes National Forest at an elevation of about 5,500 feet (1,678 m). The soil is a well-drained, sandy loam regosol, developing on ash and pumice of recent volcanic origin. Considerable amounts of rock and gravel are present. The volcanic layer is underlain at a depth of about 2 feet (0.6 m) by a buried soil which contains very few roots, thus limiting root depth to the upper ash and pumice profile.

Average annual precipitation is about 25 to 35 inches (63 to 89 cm) with much of this occurring as snow. Summers are short with little rainfall, and freezing temperatures can occur any month of the year.

Before cutting, the 146-acre (59-ha) study area supported a well stocked (200 to 250 ft^2 of basal area per acre; 46 to 57 m^2 per hectare) stand of mountain hemlock, grand fir, western white pine (*Pinus monticola* Dougl. ex D. Don), and lodgepole pine (*Pinus contorta* Dougl.) that averaged about 25,000 gross bd. ft. (Scribner) per acre. There were about 100 trees per acre, of which 85 percent were mountain hemlock, 8 percent grand fir, 5 percent white pine, and 2 percent lodgepole pine. Average diameter was about 18 inches (46 cm) for hemlock and 26 inches (66 cm) for grand fir.

After cutting was completed, there were about 15 to 20 trees per acre (37 to 49 trees per hectare) remaining. About 80 percent of these were hemlock, 18 percent fir, and a few white pine and lodgepole pine made up the balance. Density of the residual stand was not uniform over the entire area, ranging from small openings to groups of trees. Slash was piled with a bulldozer and burned, resulting in abundant exposure of mineral soil over most of the area.

After cutting was completed in the fall of 1971, 43 systematically spaced, 1-milacre plots (.00041 ha) were established in the study area. On each milacre, the total number of seedlings of each species, resulting from the 1971 seedfall, was recorded in the spring and fall of 1972 and 1973. At each milacre, basal

[2/] The results reported here are based on an inventory of natural regeneration after a commercial timber sale rather than from a formal study.

area of the residual stand was measured with a 10-factor prism.

During the summer of 1973, soil moisture content was measured gravimetrically at depths of 6, 12, 18, and 24 inches (15, 30, 45, and 60 cm), and soil moisture tension (soil matric potential) was estimated from the soil moisture depletion curve for each depth. Moisture stress (xylem pressure potential) of grand fir seedlings (1 to 2 inches tall; 2.5 to 5 cm) was measured periodically during the second growing season with a portable pressure bomb as described by Waring and Cleary (1967). All measurements were taken during the hours from 0900 to 1400 P.s.t. on seedlings in full sunlight except for June 26, when stresses were measured from 0400 to 2000 hours to determine predawn values and recovery from peak stresses.

Surface temperatures of soil and litter in open areas and under groups of trees (partial shade) were determined with Tempils[3/] having melting points of 125°, 138°, 150°, and 163° F (51.7°, 58.9°, 65.6°, and 72.8° C).

The relationship of residual stand density to initial seedling establishment and survival was analyzed by fitting the data after logarithmic transformation by linear least squares to a parabolic, exponential, and power curve model and selecting the model that accounted for the most variation in seedling numbers.

RESULTS AND DISCUSSION

Seedling Establishment and Survival

As a result of the good cone crop produced by upper slope species in 1971,[4/] an average of almost 4,000 seedlings per acre (9,880 per hectare) (total of both species) were found the following spring (table 1). About 70 percent of these seedlings were grand fir, although only about 18 percent of the residual overstory was fir. As might be expected, the greatest mortality of both species occurred during the first summer, when 41.5 percent of the fir seedlings and almost 80 percent

[3/] Tempils are small, aspirin-sized tablets, with various melting points. Manufactured by Tempil Corporation, 132 W. 22nd St., New York, N.Y. Trade name of product is mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

[4/] See Franklin et al. (1974) for cone yield ratings of upper slope species. In 1971, cone production ranged from medium to very heavy throughout the Oregon and Washington Cascades.

Table 1.--*Average number of seedlings per acre, with standard errors, and cumulative mortality after shelterwood cut, by species and date*

	Seedlings per acre				Cumulative seedling mortality at end of:					
	1972		1973		Summer 1972		Winter 1972-73		Summer 1973	
	Spring	Fall	Spring	Fall						
	Number				*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
	2,744 ± 548	1,605 ± 429	930 ± 376	791 ± 329	1,139	41.5	1,814	66.1	1,953	71.2
k	1,186 ± 330	256 ± 111	163 ± 88	116 ± 76	930	78.4	1,023	86.3	1,070	90.2
l	3,930 ± 818	1,861 ± 484	1,093 ± 407	907 ± 342	2,069	52.6	2,837	72.2	3,023	76.9

of the hemlock died. At the end of the second growing season, 71 percent of the fir and 90 percent of the hemlock seedlings were dead. At this time, the average number of fir seedlings had been reduced to 791 per acre (1,954 per hectare), and there were only 116 hemlock seedlings per acre (286 per hectare) remaining. No white pine or lodgepole pine seedlings were found on the milacres.

It was very obvious, from casual observation of the pattern of seedling establishment in the study area, that the seedlings were not distributed uniformly over the area. Most of them were found under or near groups of overstory trees, but very few occurred in openings of any size. These observations were confirmed by analysis of the relationship between number of seedlings per milacre and overstory density. The number of grand fir seedlings initially established in the spring of 1972 and the number surviving in the fall of 1973 were exponentially related to stand density; that is, the number of seedlings per milacre increased with increasing stand density. Correlation between these variables was significant at the 1-percent level (spring 1972) and 5-percent level (fall 1973)(fig. 1). Despite other unaccounted for sources of variation such as aspect and seedbed condition on the milacres, stand density alone accounted for 73 percent of the variation in the number of grand fir seedlings established in 1972 and 57 percent of the variation in the number of seedlings surviving after two growing seasons (fig. 1).

Although there were fewer mountain hemlock than grand fir seedlings established per milacre, the same exponential relationship between seedling numbers and stand density was found for hemlock (fig. 2). More hemlock seedlings were found as the overstory became denser, and a highly significant amount of the variation (71 percent) in numbers of seedlings established in 1972 was accounted for by stand density.

The initial establishment of both fir and hemlock seedlings was favored by a denser overstory, but there was a striking contrast in the mortality of these species as related to stand density. As density of the residual stand increased from 50 to 100 ft^2 per acre (11.5 to 23 m^2 per hectare), mortality of fir seedlings at the end of 2 years decreased from 100 to 46 percent (table 2). On the other hand,

Table 2.--*Average number of seedlings per milacre and mortality by species, date, and residual stand density*

Basal area at milacre (square feet)	Seedlings per milacre				Mortality after two growing seasons	
	Spring 1972		Fall 1973			
	Fir	Hemlock	Fir	Hemlock	Fir	Hemlock
	Number				*Percent*	
0	1.0	0	0	0	100	--
10	1.2	.4	.2	.2	83	50
20	.5	.2	0	0	100	100
30	2.9	.9	.4	0	78	100
40	2.5	1.3	.5	.5	80	62
50	1.5	.3	0	.2	100	50
60	2.8	1.8	.8	0	71	100
70	4.0	1.5	1.0	0	75	100
90	13.0	3.5	6.0	0	54	100
100	6.5	6.0	3.5	0	46	100

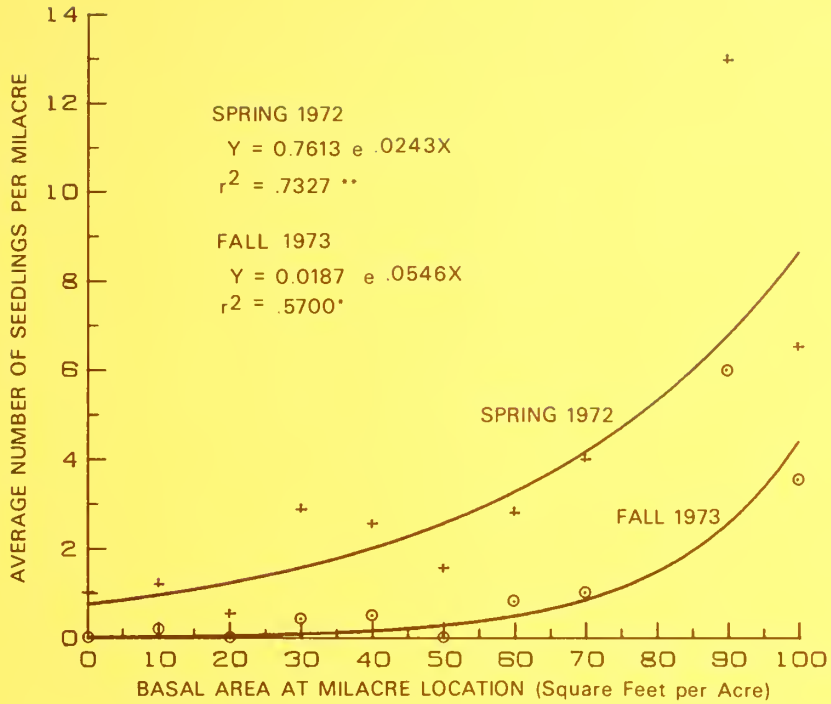

Figure 1.--Relation between density of residual stand and average number of grand fir seedlings in spring 1972 and fall 1973.

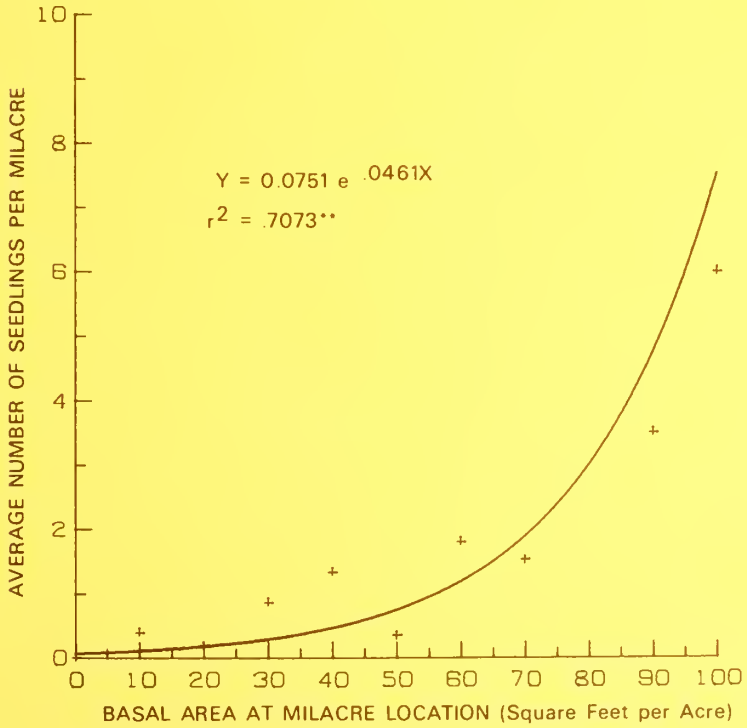

Figure 2.--Relation between density of residual stand and average number of mountain hemlock seedlings, spring 1972.

complete mortality of hemlock seedlings occurred at all stand densities above 50 ft^2 per acre (11.5 m^2 per hectare). Hemlock mortality probably would have reached 100 percent on all milacres except for some survival that can be attributed to microclimate modification by slash or a more favorable aspect.

When using the shelterwood method in the general forest zone, residual stand density should be reduced to the minimum level at which an acceptable amount of regeneration will be obtained, so that the established reproduction will not be damaged or destroyed by the removal of excess trees. Depending on the definition of acceptable stocking of reproduction, the amount of overstory needed to obtain such stocking can be estimated from the results of this study. For example, if 1,200 grand fir seedlings per acre (2,964 per hectare) are considered to be sufficient at the end of the second growing season, then residual stand density probably should be no less than 80 ft^2 of basal area per acre (18 m^2 per hectare)(fig. 1). In order to obtain adequate survival of mountain hemlock seedlings, overstory density probably should be considerably higher--more than 100 ft^2 per acre (23 m^2 per hectare)--but the density needed cannot be estimated from this study because survival was poor at all levels.

It should be emphasized that the results of this study are based on limited data from a single area and therefore are not intended to be the final answer to natural regeneration of fir and hemlock in relation to residual overstory.

The possible loss of the residual stand from windthrow should also be considered when using the shelterwood method in unmanaged stands such as these where the root depth is limited because of shallow soils. A relatively light cut is indicated because trees growing in dense stands have not developed the windfirmness needed to resist greater wind stresses resulting from heavy partial cuts; the shallow root system further increases the risk of blowdown. The risk of blowdown can be reduced by leaving dominant, full-crowned trees which are the most windfirm and also the best seed producers (Gordon 1973). An average of 1 to 2 trees per acre (3 to 5 per hectare) have been blown down in the study area in the 2 years since cutting.

Soil and Seedling Moisture Stress

Despite the severe drought which occurred in eastern Oregon in 1973, soil water was readily available throughout the summer; and seedlings never reached critical stress levels. The soil matric potential at the 6-inch (15-cm) depth was never less than -0.2 bars during the summer and was only about -0.1 or -0.2 bars at all depths at each measurement period (table 3).

The average peak moisture stress of grand fir seedlings during July and August was never less than -15 bars (fig. 3), which is well above stress levels where seedlings begin to die from drought (stress increases as values in bars become more negative). The peak stress occurred at 1300 hours at each date. Seedlings were under less moisture stress on August 31 than earlier in the summer. This is probably due to less solar radiation at this time, since soil moisture stress was relatively constant throughout the summer.

Seedling moisture stress measurements taken from 0400 to 2000 on June 26 showed the typical pattern of increasing stress until midday, followed by a decline in the afternoon (fig. 4). Stress increased from the predawn equilibrium values of

Table 3.--*Soil moisture content by weight and tension (matric potential), by depth and date (1973)* [1/]

Depth (inches)	June 26		July 13		August 7		August 31	
	Content	Tension	Content	Tension	Content	Tension	Content	Tension
	Percent	*Bars*	*Percent*	*Bars*	*Percent*	*Bars*	*Percent*	*Bars*
6	31.6	-0.1	31.7	-0.1	22.4	-0.2	21.1	-0.2
12	41.9	-.1	29.0	-.1	30.6	-.1	27.5	-.1
18	39.4	-.1	30.8	-.1	28.7	-.1	26.3	-.2
24	40.8	-.1	35.2	-.1	27.4	-.3	25.2	-.4

[1/] Each value is the mean of three replications.

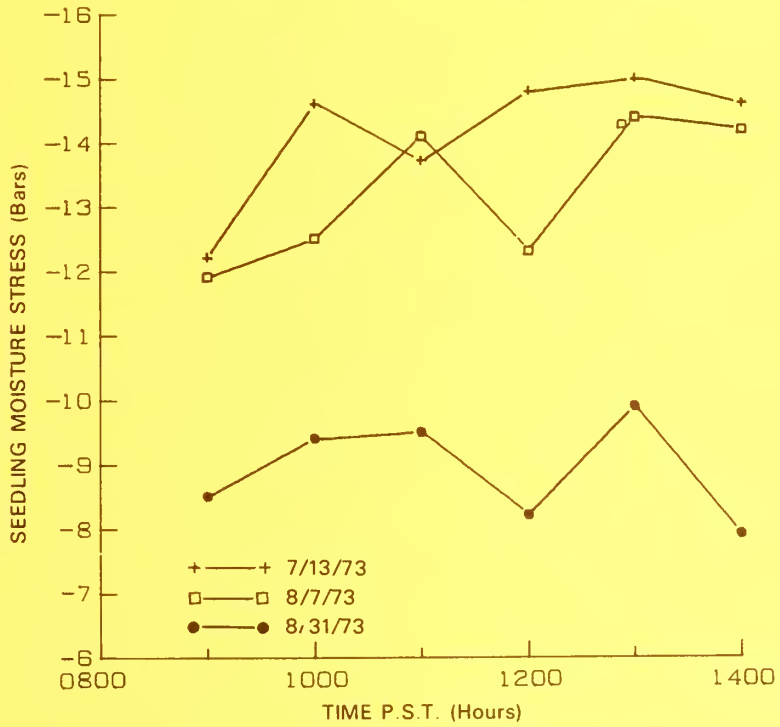

Figure 3.--Peak plant moisture stresses in grand fir seedlings on three dates, summer 1973. Each point is the mean of four seedlings.

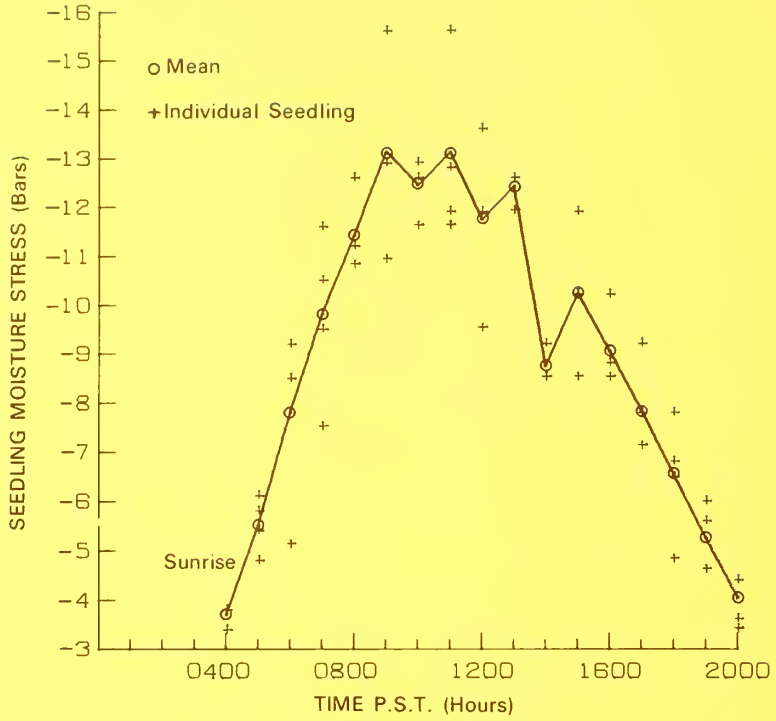

Figure 4.--Plant moisture stresses in grand fir seedlings, June 26, 1973.

-3.5 bars to -13 bars at 0900 and 1100 hours and decreased linearly after 1500 hours. Seedling recovery from peak stress values was very rapid, almost reaching the predawn value by 2000 hours. Sampling variability generally was the smallest when seedlings were not stressed. The standard error of the mean ranged from ± 0.1 bar at 0400 hours to ± 1.0 bar at 0900 hours for a mean derived from four seedlings.

The results of the soil and seedling moisture stress measurements strongly suggest that drought is not a mortality factor for grand fir seedlings after the first growing season when competing understory vegetation is absent. Similar conclusions were reached by Jones (1972) after measuring moisture stresses of mixed conifers in Arizona.

Surface Temperatures

Surface temperatures in the study area during the summer reached levels generally considered lethal to seedlings. There was little difference between the percentage of Tempils that melted in open areas and those receiving partial shade (table 4). Apparently enough direct sunlight was received in the partially shaded areas to result in surface temperatures equivalent to those found in the open areas. The temperature on the mineral soil surface was not as high as on litter in both open and partially shaded areas. None of the 163° F (72.8° C) Tempils melted on mineral soil, but 10 percent melted on litter surface, and 80 percent of the 150° F (65.6° C) Tempils melted on litter compared with only 10 percent on mineral soil.

Table 4.--*Surface temperatures, by seedbed condition and shade*

Seedbed condition	Tempil melting point (°F)			
	125	138	150	163
	- - - *Percent of pellets melted* - - -			
		Open		
Mineral soil	100	60	10	0
Litter	100	100	80	10
		Partial shade		
Mineral soil	100	40	10	0
Litter	100	100	80	10

Although surface temperatures were in the lethal range for young seedlings, no data are available regarding the length of exposure to these temperatures or the response of fir or hemlock seedlings to various high temperature-time combinations. Because it is not the temperature alone but also the duration of seedling exposure that determines mortality, no conclusions as to the importance of these temperatures in causing seedling mortality can be made at this time.

CONCLUSIONS

Although based on only a single case history, the information presented here should prove useful as a first approximation in determining density of residual overstory to leave when using the shelterwood method in upper-slope fir-hemlock stands in the central Oregon Cascades at least for regeneration of grand fir. It is apparent that seedlings of shade-tolerant species such as grand fir and mountain hemlock require a considerable amount of overstory protection in order to live through the first 2 years after germination. To obtain satisfactory numbers of grand fir seedlings, residual stand density probably should be no less than about 80 ft^2 per acre (18 m^2 per hectare).

It appears that mountain hemlock seedlings are much more sensitive to microclimatic extremes than grand fir seedlings, since hemlock survival was poor even at the highest overstory densities. These results, together with the probable windthrow loss of hemlock after heavy cutting, indicate that overstory density should be high (more than 100 ft^2 per acre; 23 m^2 per hectare) if hemlock makes up a large percentage of the stand and significant amounts of hemlock reproduction are desired. Selection of the tallest, large-crowned trees to make up the residual stand should help to minimize loss from windthrow. More experience and research is needed with shelterwood cuttings at high densities in mountain hemlock stands to determine suitable residual stocking levels.

Land managers are cautioned not to use the relationship between residual overstory and seedlings per acre as a precise predictor of regeneration success. These are only rough estimates, because seedling establishment and survival may vary greatly depending upon such factors as seed supply, weather and seedbed conditions, and animal populations.

Drought is a probable cause of seedling mortality during the first growing season if root growth does not keep pace with the drying front in the soil. After the first summer, however, there seems to be little chance of drought-caused mortality.

LITERATURE CITED

Franklin, Jerry F.
1965*a*. Ecology and silviculture of the true fir-hemlock forests of the Pacific Northwest. Soc. Am. For. Proc. 1964: 28-32, illus.

_____
1965*b*. Tentative ecological provinces within the true fir-hemlock forest areas of the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-22, 31 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

_____, Richard Carkin, and Jack Booth
1974. Seeding habits of upper-slope tree species. I. A 12-year record of cone production. USDA For. Serv. Res. Note PNW-213, 12 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

_____ and Clark E. Smith
1974. Seeding habits of upper-slope tree species. II. Dispersal of a mountain hemlock seedcrop on a clearcut. USDA For. Serv. Res. Note PNW-214, 9 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Gordon, Donald T.
1973. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings. USDA For. Serv. Res. Pap. PSW-90, 22 p., illus. Pac. Southwest For. & Range Exp. Stn., Berkeley, Calif.

Gratkowski, H. J.
1958. Natural reproduction of Shasta red fir on clear cuttings in southwestern Oregon. Northwest Sci. 32: 9-18.

Jones, John R.
1972. Moisture stresses in Arizona mixed conifer seedlings. USDA For. Serv. Res. Pap. RM-86, 8 p., illus. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.

Waring, Richard H., and Brian D. Cleary
1967. Plant moisture stress: evaluation by pressure bomb. Science 155: 1248, 1253-1254, illus.

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USDA FOREST SERVICE RESEARCH NOTE

PNW-230 June 1974

LOW-COST COUNTER ASSEMBLY FOR CURRENT-METER MEASUREMENTS

W. B. Fowler, *Principal Meteorologist*

ABSTRACT

A low-cost (under 35 dollars) counter assembly designed to replace earphones for current meter measurements is described. The simple, two-transistor circuit operates over at least a -20° to +40° C temperature range. The digital readout is helpful, especially at times of high stream velocities.

Keywords: Measurement systems (streamflow), current meter.

Prices for streamflow instrumentation indicate a considerable premium for accessories which free the operator from the tedium and potential inaccuracies of counting current-meter earphone signals. These accessories include electronic rate meters calibrated in terms of velocity, as well as recorders which display each contact closure. To meet a requirement of local Wenatchee National Forest personnel, several easily constructed, low-cost counters were fabricated to serve as current-meter readouts. The procedure of averaging over a period of time, either by counting pulses aurally or by accumulating pulses in some electro-mechanical device, was suggested as preferable to, or at least as acceptable as, an instantaneous meter reading, especially in small streams with substantial velocity fluctuations. Also, current meters with single contacts per rotation do not adapt well to electronic rate meter operation.

The circuit in figure 1, adapted from Mitchell,[1/] differs from most monostable circuits in that both transistors operate in unison; therefore, current drain (except for minor leakages) is a minimum when no pulse is received at the input. Counter assemblies operated satisfactorily over a temperature range of -20° to $+40^{\circ}$ C. Alkaline batteries are best for operation at low temperatures and long service life. Battery life obviously depends on condition of use; the C size battery should operate over 10 hours continuously at the highest counter rate, 20 counts per second. This is equivalent to about 600 1-minute counts. The circuit is easily constructed on a perforated circuit board; the printed circuit board shown in figure 3 was surplus from another device.

Figures 2 and 3 are photos of two views of a completed counter. The on-off switch is a momentary contact type requiring continuous pressure during the counting period. The second switch allows selection of a contact closure for each revolution of the rotor or of each fifth revolution as determined by the gearing inside the meter head. In most instances, this switch may be an unnecessary detail since the counter circuit is capable of counting pulses from each revolution up to the rated speed of most current meters. The stop watch is fixed to the counter panel by a nylon fastener,[2/] placing all controls in easy view. The stop watch would not normally be reset; any equal time period would suffice for the counting period. For one-hand operation, a neck strap is advisable.

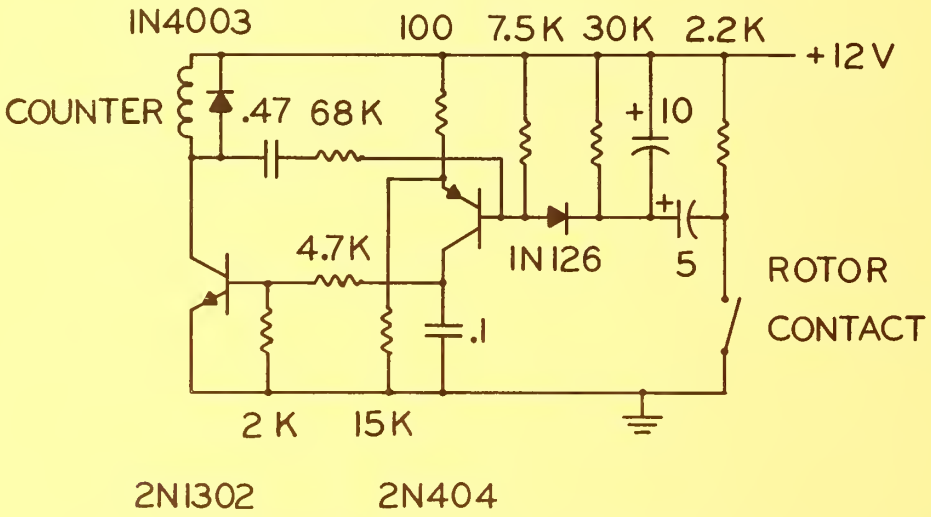

Figure 1.--Schematic of counter assembly.

[1/] W. P. Mitchell. Power one-shot. In *Sourcebook of Electronic Circuits*, (J. Markus, ed.), p. 432. McGraw-Hill, Inc., New York, 1968.

[2/] Velcro® Hook and Loop Type Fastener. Mention of product by name does not imply endorsement by U.S. Department of Agriculture.

Figure 2.--Exterior view of completed counter assembly.

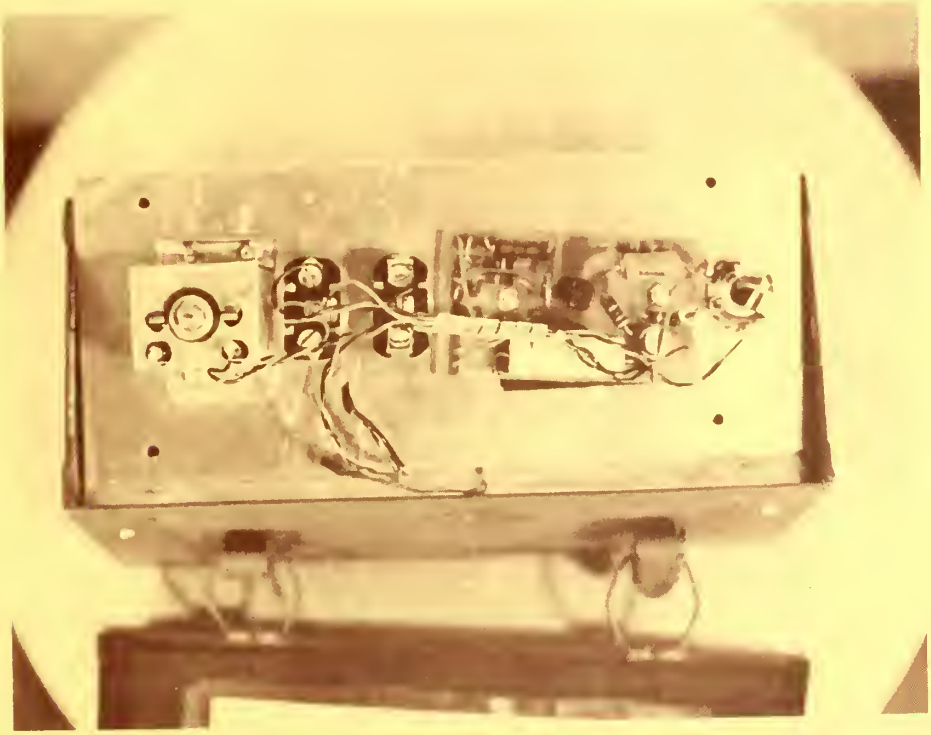

Figure 3.--Interior view. Layout of components is not critical.

Most current meters now in use probably do not have the newer sealed magnetic switches in the contacting mechanism. A variable resistance due to the water's conductivity is always across a nonsealed switch. Resistances parallel to the contacts as low as 2,000-3,000 ohms do not affect operation of the circuit. Expressed as conductivity, this is a value about 50 times greater than measured conductivities of our local stream. Contact noise can be a problem at the very lowest of rotor speeds (several counts per minute). At these low rotor speeds, the actual cup rotation is often visible (in clear streams) or the counter "chatter" used to signal a completed revolution. This "chatter" occurs because the circuit recognizes the poor contact as a series of separate events and reacts accordingly. Some filtering is provided by the large input capacitors to reduce contact noise. The large input capacitors cause the circuit to depart from true monostable action. "On" time of the circuit is determined, not by the coupling capacitor, as is customary, but by the charging of the input capacitors. For this application, however, the distinction is not important. For best results, especially at the lowest of rotor speeds, badly pitted or burned contacts should be replaced or refurbished. Further contact damage will be a minimum due to the small input current of this circuit.

Parts List

1. Resistors 10% ½ watt
2. Electrolytic capacitors - 15 volts minimum rating, observe polarity
3. .47; .1 capacitor - Mylar - 50V
4. Counter, 3 or 4 digit, push button reset, 12V DC, low current requirement, e.g., Hecon G856002-3 12DC

Electrically equivalent semiconductors may be substituted for devices listed. The counter is the most expensive circuit component, $15 to $25 depending on manufacturer. The Hecon unit lists for about $21. Total cost of other components should not exceed $12.

GPO 990-910

USDA FOREST SERVICE RESEARCH NOTE

.79:PNW-231

PNW-231 June 1974

OLD-GROWTH COAST DOUGLAS-FIR LOG GRADES--A DISTRIBUTION ANALYSIS OF EXISTING LOG GRADES WITH A NEW FOUR-GRADE SYSTEM

by

M. Wallace Burck, *Forestry Technician*

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ABSTRACT

Information is presented to allow veneer and sawmill processors and buyers of Coast Douglas-fir timber to compare distribution of logs by two grading systems. One system is the presently used Peeler-Sawmill system; the other is a new four-grade system developed by the Pacific Northwest Forest and Range Experiment Station.

Keywords: Log grading, Coast Douglas-fir.

REST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

The Pacific Northwest Forest and Range Experiment Station has developed a new four-grade log cruising system for old-growth Coast Douglas-fir (*Pseudotsuga menziesii*) sawtimber.[1/]

Of interest to log buyers and processors, this Research Note compares the distribution of woods-length logs graded by the existing Peeler-Sawmill system[2/] to bucked logs graded by a new four-grade system.

Approximately 1,000 old-growth[3/] study trees were selected for log grade (see footnote 1) and product recovery studies from about 100 sample areas in Washington, Oregon, and California. About three-quarters of these trees were sawn at 10 sawmills, and the remaining one-quarter were processed at 10 veneer plants.

DISCUSSION

The information presented in this note is a tabulation of the 6,509 logs by two grading systems. Woods-length logs that were considered cull by the scalers have been omitted, even though after bucking one or more processing lengths were found to be merchantable (33-1/3 percent sound). The distribution of the logs graded under each system is shown as a percentage of the other system.

The following tabulation gives the number of processed or mill-length logs bucked from woods-length logs in each of the Peeler-Sawmill grades.

Grade	Number of: Woods-length logs	Bucked logs (mixed grades)
1 Peeler	96	139
2 Peeler	108	172
3 Peeler	445	773
Special Peeler	214	400
1 Sawmill	5	10
2 Sawmill	1,776	3,039
3 Sawmill	1,248	1,976
Total	3,892	6,509

All logs placed in the highest grade under one system do not automatically fall into the highest grade under the other system. In developing the new grades, we found

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[1/] Paul H. Lane, Richard O. Woodfin, Jr., John W. Henley, and Marlin E. Plank. New timber cruising grades for Coast Douglas-fir. USDA Forest Service Research Paper PNW-151, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1973.

[2/] USDA Forest Service R-6 supplement to National Forest Log Scaling Handbook for Westside Log Scaling, October 1965. USDA Forest Service Log Grade Description for Douglas-fir. Form R-6 2440-190 (March 1965).

[3/] Old growth is defined as trees generally more than 100 years old.

that some logs graded by the existing system had high value product recovery but were often placed in a lower grade. This was due to the existing log grade specifications and not to errors in application of the grades.

Figure 1 shows the study logs in each of the existing log grades as distributed among the new four-grade log system.[4/] This gives the percentage of processed or mill-length logs graded by the new system that were produced when woods-length logs graded by the existing Peeler-Sawmill system were bucked.

As shown in figure 1, a percentage of Grade 2 logs in the new system appears in the existing No. 1 Peeler log grade. From the 139 processed or mill-length logs that were bucked from the woods-length No. 1 Peeler grade logs, 110 logs or 79 percent were Grade 1 of the new system. The remaining 29 logs or 21 percent were graded as Grade 2. Likewise, small percentages of the new system's higher grade logs are distributed throughout the existing Peeler-Sawmill log grades. These differences resulted from grading characteristics in the new specifications such as basal scars, burls, butt swell, and logs being adjacent to cull logs.

[4/] A synopsis of the new four-grade Coast Douglas-fir timber cruising grades is located at the end of this note.

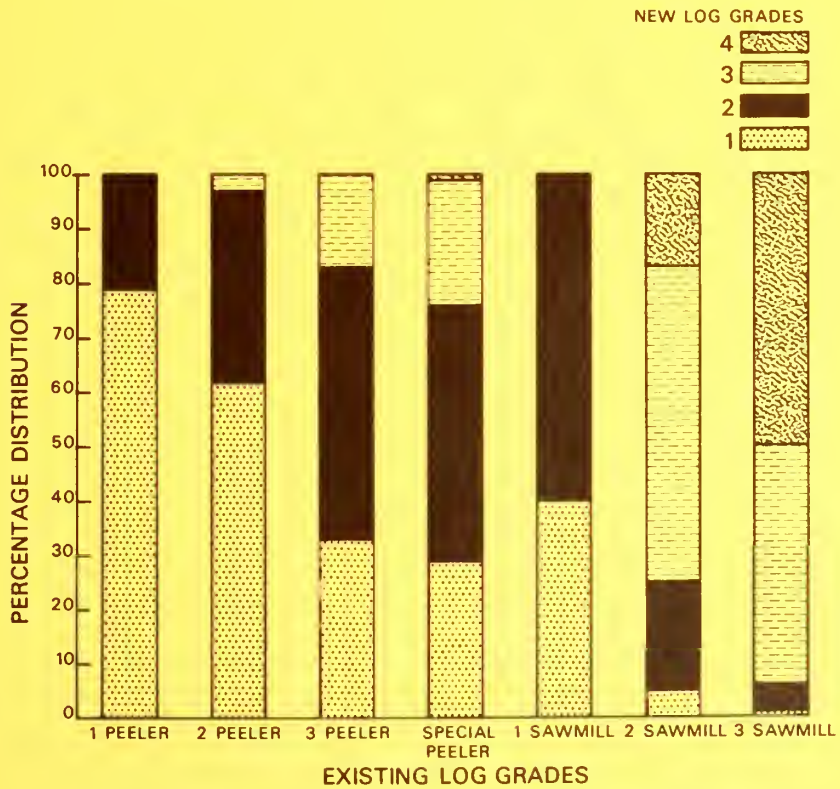

Figure 1.--Percent distribution of logs by the new grades within each of the existing grades.

These same grading characteristics apply to the other grades shown in figure 1. For example, in the No. 2 Peeler logs 3 percent of apparent Grade 2 logs dropped to Grade 3 in the new system because they were adjacent to a cull log.

In the No. 2 Sawmill and No. 3 Sawmill log grades, there was a small percentage of Grade 1 and 2 logs by the new system. These were high quality logs, free of degrading characteristics; but diameter limitations in the existing log grades caused these logs to be placed in the Sawmill log grades.

Figure 2 shows the study logs in each of the new log grades as distributed among the existing log grades. For example, 1,381 logs were graded as Grade 2 under the new system, and 28 percent of these or 385 logs came from woods-length logs graded as No. 3 Peeler. However, as shown in figure 1, about 50 percent or 385 logs of the woods-length No. 3 Peeler logs produced processed or mill-length Grade 2 logs.

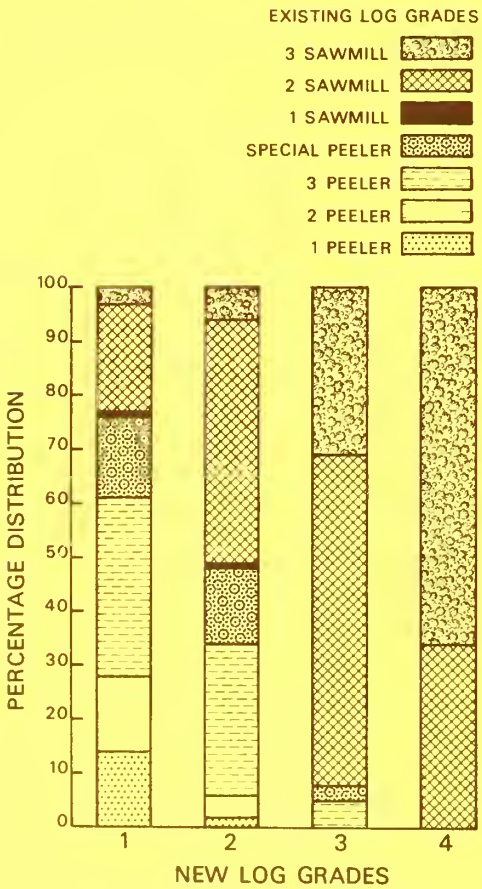

Figure 2.--Percent distribution of logs by the existing grades within each of the new grades.

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

January 1973

P. H. Lane, R. O. Woodfin, Jr., J. W. Henley, and M. E. Plank

TIMBER CRUISING GRADES FOR COAST DOUGLAS-FIR[1/]

General grade specifications.--These log grades were developed for live, standing, old-growth coast type Douglas-fir. They can be applied to recently killed or blown down timber that has not deteriorated to the point that it is difficult to apply the grading specifications properly or that product yields would be materially affected.

1. Grades are for 16-foot "log" lengths, including trim allowance, as cruised in standing trees. Do not apply these grades to cull logs (logs less than one-third sound by cruise volume).
2. Although log diameter is not a grading criterion, the effect of grade and log size can best be reflected in local performance tables.
3. Some grading specifications are applied by log "faces." A log face is one-quarter of the circumference for the full length of the log.

Application of grades.--The following are suggested steps:

1. Size up each log with respect to knots, determining the poorest and best faces.
2. Establish grading faces. Once the grading faces on a log are established, they cannot be shifted, except for burls.
3. Apply knot or indicator specifications to determine preliminary grade of log; apply other criteria such as scars, conks, etc., to establish final grade.

Definitions:

1. Knots are sound, live, or dead limbs or limb stubs outside knot cluster.
2. Knot indicators are bark distortions which indicate underlying knots. Size is the vertical diameter of the depression in the center of the distortion.
3. Knot clusters are at least three limbs or stubs, 1 inch or larger, growing in an inseparable group. Knot size in the cluster is not considered.
4. Indicator clusters are three or more knot indicators usually well defined by a distorted bark pattern and surface rise.
5. Scars are injuries caused by fire, logging, frost, and lightning. Their condition, location, and size determine whether they are degrading and considered in the specifications or are superficial and can be disregarded.
   A degrading scar has underlying wood that is decayed, excessively pitchy, severely checked, or otherwise injured to the extent that lumber or veneer recovery would be affected.
   A superficial scar is shallow, open, sound, and of relatively recent origin and, in the cruiser's judgment, does not affect lumber or veneer recovery.
6. Conks indicate the presence of rot.
7. Cankers are mistletoe or rust lesions characterized by distorted bark, callous tissues, and pitch flow.
8. Rotten knots are live or dead limbs or stubs showing rot.
9. Sound burls are round or elliptical growths that protrude from the log surface and show no signs of decay.
10. Unsound burls are burls with decay and/or heavy pitch.
11. Bumps and bulges are bark covered surface swellings outside normal taper or normal butt swell.
12. Epicormic branches are sprout-type limbs, usually a half inch or less in diameter.
13. Holes are the result of bird peckings or insect activity into the cambium.

1/ For a more complete description of these grades refer to Research Paper PNW-151 by Paul H. Lane, Richard O. Woodfin, Jr., John W. Henley, and Marlin E. Plank.

GRADING SPECIFICATIONS FOR COAST DOUGLAS-FIR

<table>
<tr><th>Log characteristic</th><th>Grade 1</th><th>Grade 2</th><th>Grade 3</th><th>Grade 4</th></tr>
<tr><td>Knot (sound)</td><td>One allowed if 1 inch or less
or
one larger than 1 inch if within 6 inches of log end.</td><td>None allowed on two faces. Knots larger than 2 inches must be confined to upper or lower half of one face.</td><td rowspan="2">Knots (sound or rotten) larger than 3 inches must be confined to one face.</td><td rowspan="12">Any merchantable log not meeting requirements for Grade 3.</td></tr>
<tr><td>Rotten knot</td><td>None allowed.</td><td>None allowed unless log is otherwise Grade 1.</td></tr>
<tr><td>Knot indicator</td><td>If larger than 1 inch, must be confined to no more than two faces.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Knot cluster</td><td>None allowed.</td><td>One if confined to one face.</td><td>Any number if confined to no more than two faces.</td></tr>
<tr><td>Indicator cluster</td><td>One allowed if confined to one face.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Degrading scar</td><td>None allowed from ground line to 8 feet. Above 8 feet: No limit for sound scars 6 inches x 6 inches or smaller; larger sound scars must be confined to either one face or not more than two faces in any one-fourth of log length. No rotten scars allowed.</td><td>All scars having rot must be confined to one face.</td><td>No requirements.</td></tr>
<tr><td rowspan="2">Sound burl[2/]</td><td colspan="3">Disregard burls if less than 6 inches in diameter.</td></tr>
<tr><td>If larger than 6-inch diameter, must be confined to one face.</td><td colspan="2">All larger than 6-inch diameter must be confined to three faces.</td></tr>
<tr><td>Conk, canker, and unsound burl</td><td>None allowed.</td><td>None allowed unless log is otherwise Grade 1.</td><td>No requirements</td></tr>
<tr><td>Bump and bulge</td><td>None 6 inches x 6 inches or larger allowed from ground line to 8 feet. No requirements above 8 feet.</td><td colspan="2" rowspan="2">No requirements.</td></tr>
<tr><td>Epicormic branches and holes</td><td>Must be confined to one face.</td></tr>
</table>

1/ A log meeting specifications for either Grade 1, 2, or 3 is lowered one grade if adjacent to a cull log.

2/ When burls are considered, log faces can be shifted from the faces initially established for knots or other characteristics.

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USDA FOREST SERVICE RESEARCH NOTE

3.79:PNW-232

PNW-232 June 1974

PROPOSED HARVESTING GUIDES BASED UPON AN ENVIRONMENTAL CLASSIFICATION IN THE SOUTH UMPQUA BASIN OF OREGON

Richard E. Carkin, *Forester*

and

Don Minore, *Plant Ecologist*

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ABSTRACT

Success or failure of forest regeneration on clearcuts is significantly related to soil depth and texture, elevation, solar radiation, moisture, and temperature of the preharvest environment. Regression equations express these relationships. They should be useful in comparing potential regeneration difficulty on areas to be harvested.

Keywords: Management planning (- regeneration), clearcutting systems.

REST SERVICE - U.S DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Clearcutting forest stands in parts of southwestern Oregon exposes the site to environmental extremes--frost, heat, drought--that limit establishment of regeneration. Tree seedlings may be established on such sites by leaving an overstory of mature trees to protect the site during the regeneration period (Franklin and DeBell 1973, Minore 1973, Williamson 1973). Unfortunately, problem sites are difficult to identify before harvesting.

The study reported here is part of a continuing research program aimed at improving forest regeneration in southwestern Oregon. The approach utilizes a proposed environmental classification in the South Umpqua basin (Minore 1972). In that proposal environments were classified using indices based on elevation, temperature, moisture, solar radiation, and soil type. In this paper we have related success or failure of regeneration on clearcuts to the apparent preharvest environment. Some significant relationships were found. It appears possible, therefore, to classify the preharvest environment and, based on this classification, make at least a rough prediction of regeneration success after clearcutting.

METHODS

The study area is the portion of the South Umpqua basin above Canyonville, Oregon. It is bounded on the west by North Myrtle, Canyon, and Starveout Creeks, on the south and east by the South Umpqua - Rogue divide, and on the north by the South Umpqua - Little River divide (fig. 1). Every clearcut logged before 1969 on Bureau of Land Management and Umpqua National Forest lands within this area was examined on aerial photographs or in the field to find situations where all or part of a clearcut

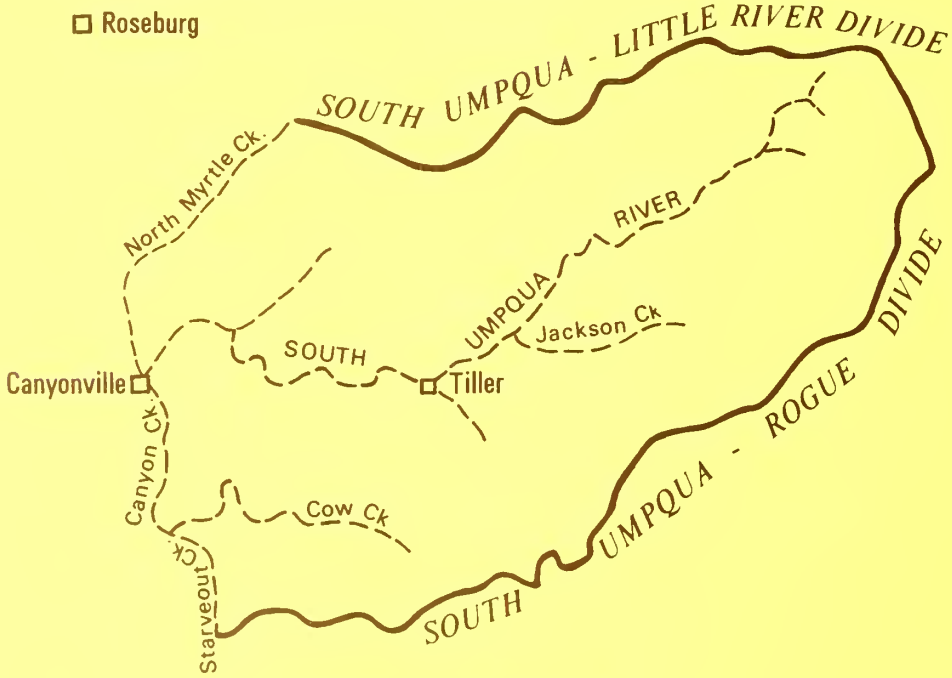

Figure 1. The study area.

area and an adjacent uncut stand were located on the same slope, aspect, and soil series. We assumed the environment under the uncut stand was the same as the preharvest environment on the matching clearcut area. This permitted effective use of native plants under the uncut stand as indicators of moisture and temperature. Actually, most plant species survive logging and slash burning and are present on clearcuts, but they become scattered and difficult to classify (Dyrness 1973). In studying eligible clearcut areas and adjacent stands, we made the following assumptions:

a. Environmental factors strongly influence the success or failure of forest regeneration after clearcutting.
b. Three or more years after harvesting, differences in clearcut stocking result from environmental differences between areas.
c. Vegetation now present in the uncut stand was present in the clearcut area before logging.
d. The best available reforestation techniques were used on the clearcut areas sampled. (As all sample clearcuts were at least 3 years old in 1972, these techniques were the ones commonly used before 1969).

Most clearcut boundaries coincided with topographic discontinuities, and only about 10 percent of the clearcuts within our study area contained areas with the same slopes, aspects, and soil series as adjacent uncut stands. The number of eligible clearcuts was further reduced by our restricting the sample to those logged before 1969. This allowed at least 3 years for planted stock and natural regeneration to become established on areas where environmental factors and regeneration were compared. The 57 areas that met all sampling criteria were selected without any attempt to stratify by slope, aspect, soil series, age, or location within the study area and were harvested between 1950 and 1968 (table 1). Of the selected clearcuts, 47 (83 percent) were planted at least once after harvesting, 15 (26 percent) were seeded as well, 6 (10 percent) were seeded without planting, and 4 (7 percent) were left for natural regeneration.

The following were measured on each clearcut area:

a. Elevation determined with an altimeter calibrated against known benchmarks.
b. Slope in percent.
c. Aspect.

Table 1.--*Age distribution of sampled clearcuts*

Year of harvest	Number of clearcuts	Year of harvest	Number of clearcuts
1950	1	1960	2
1951	1	1961	1
1952	4	1962	3
1954	3	1963	3
1955	3	1964	5
1956	13	1965	1
1957	2	1966	3
1958	2	1967	1
1959	7	1968	2

d. Potential solar radiation estimated by using measured slope and aspect to obtain radiation index from the tables of Frank and Lee (1966) for lat. 43° N.
e. Soil depth, texture, and series determined by digging pits in both clearcut and adjacent stands.
f. Temperature and moisture indices determined after identifying and listing plant indicator species present in the adjacent uncut stand. Minore's 1972 procedure was used (see appendix).

Additional general observations of stand conditions and plant species associated with stocked and unstocked clearcut areas were recorded throughout the study.

Stocking of conifer seedlings in each clearcut sample area was determined by running equally spaced parallel compass lines across the area. At least 20 circular 1/250-acre (1/620-hectare) plots were established at equal intervals along the lines. Spacing of these lines and plots (1/2 or 1 chain (10 or 20 meters)) varied with size of the clearcuts in order to sample adequately that part of each having the same slope, aspect, and soil series as the adjacent uncut stand. None of the plots were located on parts of the clearcut topographically or geologically dissimilar to the uncut stand. Tree seedlings were counted on each plot, and the plot was classified as stocked or unstocked. As old seedlings are more likely to survive than young ones, our stocking standards were weighted by seedling age. To be classified as stocked, a plot had to contain one of the following:[1/]

One tree at least 4 years old
Two trees at least 3 years old
Three trees at least 2 years old
Five trees at least 1 year old

Stocking percent for each clearcut sample area was determined by dividing the number of stocked plots by the total number of plots established on that area. For example, if 25 plots were established and only 5 of them were stocked, stocking would be 20 percent.

Quantitative data were grouped by soil depth and texture. Then stepwise multiple regression analyses were calculated to test the significance of relationships between the independent variables (elevation, moisture index, temperature index, radiation index[2/]) and the dependent variable (stocking percent). Relationships involving interactions between variables and squared variables also were tested.

RESULTS

Stocking ranged from 0 to 100 percent on the sampled clearcut areas--39 were at least 50-percent stocked; 18 had less than 50-percent stocking. The influence of environment upon stocking was readily apparent. One, harvested in 1954 and left for natural regeneration, was 86 percent stocked when sampled in 1972. Another, harvested in 1959, was only 9 percent stocked in 1972 after being planted three times, seeded, treated with atrazine, scarified by bulldozer, and planted again. Obviously, the environment was favorable for regeneration on the first and unfavorable on the second.

Regression equations indicated that elevation, radiation, moisture, and temperature were significantly related

[1/] These stocking standards were derived from those used in U. S. Department of Agriculture National Forest regeneration surveys. As our results are based on these standards, readers using different standards may find it necessary to compare stocking standards in the field before using the equations listed in the results section. General results should not differ with stocking standards, but small percentage differences probably will occur when different standards are used.

[2/] Slope and aspect are included in the radiation index.

to stocking percent on the sample areas:

Shallow soils

Stocking percent = 98.98 + 0.016 (elevation) - 227.48 (radiation index)

(R^2 = 0.522, standard error = 18.57)

Deep clay loams and clays

Stocking percent = -221.94 + 57.78 (moisture index) - 2.43 (moisture index)^2 - 8.57 (radiation index) (moisture index)

(R^2 = 0.621, standard error = 18.71)

Deep loams and sands

Stocking percent = 91.86 - 0.003 (elevation) (temperature index) -5.42 (radiation index) (temperature index) + 0.64 (temperature index)(moisture index)

(R^2 = 0.426, standard error = 22.06)

The above equations are only estimating aids, not precise prediction formulas. As the coefficient of determination (R^2) values indicate, these equations account for only about half of the variation involved in the observed stocking-environment relationships. Unmeasured variables such as seeding and planting methods, condition of the planting stock, soil temperature at time of planting, and weather conditions after planting account for the other half.[3/] Stepwise multiple regression standard error terms are difficult to interpret and apply, but those listed indicate that the equations are not precise. For example, the stocking obtained on a clearcut area with shallow soils probably will be within 18.6 percent of the calculated value only about two out of three times.

[3/] The regression variables are assumed to be measured without error.

Subjective examination and interpretation of our field notes and data indicated that poor stocking (less than 60-percent by the standards used) usually was associated with plant moisture indices below 9.0. Shallow soils and/or the presence of *Berberis aquifolium*, *Rhus diversiloba*, or *Lonicera hispidula* frequently were found where clearcuts were poorly stocked. Well-stocked clearcuts usually were associated with deep soils where the moisture index was above 9.0.

DISCUSSION AND CONCLUSIONS

Although the regression equations significantly relate measured environmental variables to observed stocking percentages, variation from the regression line may be substantial in predicting stocking levels in individual situations. The equations are recommended only as an adjunct to other information available to the land manager, to supplement his judgment based on experience in the local area. The equations also should be useful in comparing potential regeneration difficulty on areas to be harvested. Where the equations yield low stocking percentages, regeneration probably will be more difficult than where they yield high percentages.

The procedures described above and in the appendix constitute a first approximation to the difficult task of prescribing optimal harvest treatments for forested areas in the South Umpqua basin. We plan to continue research on this problem and hope to reduce variation and more accurately relate regeneration success to environmental conditions. In the meantime, we would appreciate receiving the ideas, comments, and observations of foresters using these procedures in the field.

LITERATURE CITED

Dyrness, C. T.
1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54(1): 57-69, illus.

Frank, Ernest C., and Richard Lee
1966. Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. USDA For. Serv. Res. Pap. RM-18, 116 p., illus. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.

Franklin, Jerry F., and Dean S. DeBell
1973. Effects of various harvesting methods on forest regeneration. *In* Richard K. Hermann and Denis P. Lavender (eds.), Even-age management symposium, p. 29-57. Oreg. State Univ., Corvallis.

Hitchcock, C. Leo, Arthur Cronquist, Marion Ownbey, and J. W. Thompson
1955-69. Vascular plants of the Pacific Northwest. 5 vols., illus. Seattle: Univ. Wash. Press.

Minore, Don
1972. A classification of forest environments in the South Umpqua basin. USDA For. Serv. Res. Pap. PNW-129, 28 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

———
1973. Mixed conifers of southwestern Oregon. *In* Silvicultural systems for the major forest types of the United States, p. 10-13. U.S. Dep. Agric. Agric. Handb. 445, 114 p.

Peck, Morton Eaton
1961. A manual of the higher plants of Oregon. 2d ed., 936 p., illus. Portland, Oreg.: Binfords & Mort.

Williamson, Richard L.
1973 Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. USDA For. Serv. Res. Pap. PNW-161, 13 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

APPENDIX

VEGETATION TALLY SHEET

Vegetation tally sheet for determining South Umpqua temperature and moisture indices. To use, circle the values opposite each species[4/] present, total circled values in each column, and divide by the number of circles in that column.

Species	Temperature value	Moisture value
Abies magnifica var. *shastensis*	1	--
Actaea rubra	1	--
Adenocaulon bicolor	--	10
Amelanchier alnifolia	--	10
Anemone deltoidea	4	15
Arbutus menziesii	8	--
Arctostaphylos canescens	4	10
Arnica cordifolia	4	10
Berberis aquifolium	12	5
Berberis nervosa	--	10
Castanopsis chrysophylla	--	10
Ceanothus integerrimus	--	10
Clintonia uniflora	--	15
Corallorhiza maculata	--	10
Cornus nuttallii	4	10
Cynoglossum grande	8	--
Disporum hookeri	4	--
Festuca californica	8	5
Galium oreganum	1	--
Gaultheria shallon	12	10
Goodyera oblongifolia	4	--
Habenaria unalascensis	4	--
Ligusticum apiifolium	4	--
Lonicera hispidula	12	1
Montia sibirica	4	--
Osmorhiza chilensis	--	10
Pachystima myrsinites	4	--
Pinus ponderosa	4	5
Psoralea physodes	--	10
Pyrola picta	4	10
Quercus chrysolepis	8	--
Quercus kelloggii	8	--
Rhododendron macrophyllum	--	15
Rhus diversiloba	12	1
Rubus nivalis	--	15
Satureja douglasii	12	--
Smilacina stellata	--	15
Taxus brevifolia	4	--
Thuja plicata	4	15
Tiarella unifoliata	1	--
Tsuga heterophylla	4	15
Vaccinium parvifolium	--	10

4/ Nomenclature follows Hitchcock et al. (1955-69) and Peck (1961).

Species	Temperature value	Moisture value
Valeriana sitchensis	1	--
Xerophyllum tenax	4	--
Total, circled values		
Number of species circled		
Average*		

*Average = $\frac{\text{Total, circled values}}{\text{Number of species circled}}$ = Index

Example: A stand with *Adenocaulon*, *Anemone*, *Arbutus*, *Arctostaphylos*, *Cornus*, *Goodyera*, *Lonicera*, *Rhus*, *Smilacina*, *Taxus*, *Vaccinium*, and *Xerophyllum* would have a plant temperature index of 6.2 and a plant moisture index of 9.0.

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3.79: PNW-233

PNW-233

November 1974

STOCKABILITY EQUATIONS FOR CALIFORNIA FOREST LAND

by

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and

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ABSTRACT

Equations are presented for predicting the stocking capacity of commercial forest land in five geographic areas in California from site index, physical characteristics, and the presence of certain indicator plants. The equations can be used to identify areas incapable of supporting "normal" stocking. For such areas, equations provide adjustments of anticipated timber yields.

Keywords: Stocking density, indicator plants.

INTRODUCTION

In 1973, we reported on a procedure for predicting stocking capacity from multiple regression equations based on site index, elevation, and the presence of certain indicator plants (MacLean and Bolsinger 1973). The equations proved useful for (1) identifying areas incapable of supporting "normal" densities of stocking and (2) quantifying and adjusting normal yield tables to allow for this limitation on stocking capacity. The report included equations for use in Shasta and Trinity Counties, California. This paper presents equations for use in other parts of the State. We include the equation, in slightly altered form, for Shasta and Trinity Counties for the reader's convenience.

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For a full understanding of the procedures, the reader should refer to the earlier paper, "Productivity on Sites with a Low Stocking Capacity" (MacLean and Bolsinger 1973).

The equations presented here predict the stocking capacity of a site expressed as a proportion of the stocking capacity of sites described in a normal yield table. For areas without stocking limitations, the equations should predict a relative stocking capacity that is within ± 20 percent of "normal." We assume that a limitation on stocking exists whenever the relative stocking capacity is less than 0.8 of normal. For such areas, normal yield table predictions of yield are discounted by the predicted relative stocking capacity. If, for example, the predicted stocking capacity of a Douglas-fir[1/] site is 0.5, then the normal yield table predictions of basal area, number of trees, and yield should all be multiplied by 0.5.

THE EQUATIONS

Five equations follow. To use the equations, select a normal yield table appropriate to the site and species. The stocking capacity of the stands described in the normal yield table can be expressed as stand density index--a measure of relative stand density developed by Reineke (1933). The normal stand density index for the yield table chosen is a variable in each equation. Normal stand density indices for yield tables commonly used in California are:

Species and Source	
Douglas-fir (Schumacher 1930)	400
Douglas-fir (McArdle et al. 1961)	370
Lodgepole pine (Dahms 1964)	460
Ponderosa pine (Meyer 1961)	365
White fir (Schumacher 1926)	565
Mixed conifer (Dunning 1933)	479

All other independent variables have a value of 1 if present and 0 if absent--except for elevation which is recorded to the nearest 100 feet, Dunning's site index (Dunning 1942) which is recorded to the nearest foot (even when estimated to the nearest 25-foot class) and universal transverse mercator (U.T.M.) coordinate distance north[2/] to the nearest 1000 meters. Plant groupings are recorded as present if any species in the group is found.

The geographic area where each equation is applicable is shown in figure 1. Area 3 bounds area 4 on the Sierra Divide. Otherwise, the boundaries conform to either county lines or the lower limits of commercial forest. Use of the equations outside these areas is not recommended.

[1/] Scientific and common names of plants are listed on page 8.

[2/] U.T.M. grids appear on U.S. Army Map Service maps and most U.S. Geological Survey quadrangles.

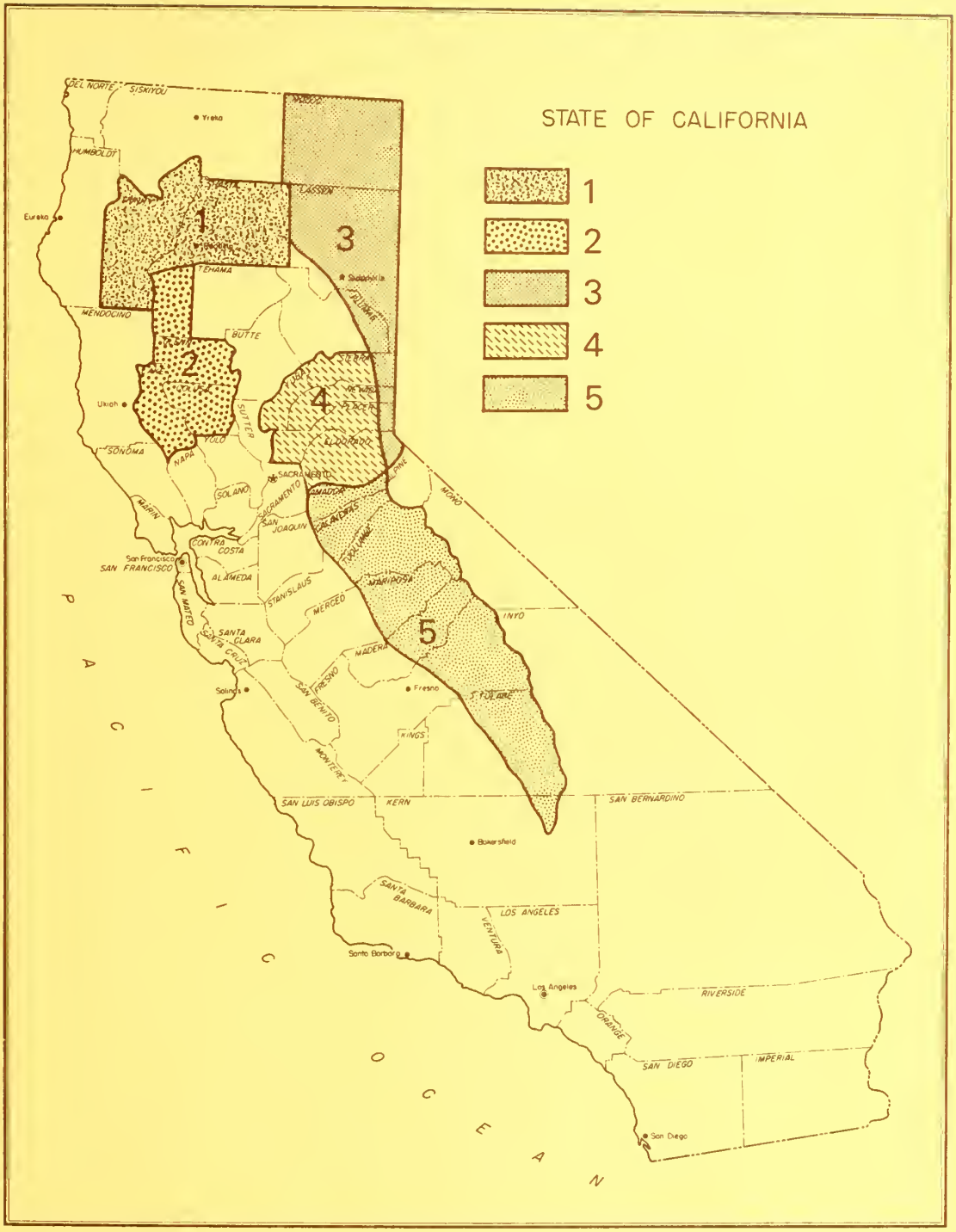

Figure 1.--State of California showing the five geographic areas sampled for this study.

AREA 1 (SHASTA AND TRINITY COUNTIES)

$$\text{Relative stocking capacity} = \frac{1}{NSDI}(-2 - .47X_1 - 84X_2 + 62X_3 + 99X_4 + 39X_5 + 92X_6 + 64X_7 + 33X_8 + 61X_9 + 32X_{10} - 44X_{11} + 0.0719X_{12} + 0.00045X_{13} - 0.0000082X_{14})$$

When: $NSDI$ = normal stand density index

X_1 = *Ceanothus cuneatus*, *Cercocarpus betuloides*, or *Cercocarpus ledifolius*

X_2 = *Cercis occidentalis* or *Ceanothus lemmonii*

X_3 = *Quercus garryana*, *Q. garryana* var. *breweri*, or *Q. wislizenii*

X_4 = *Abies magnifica*

X_5 = *Pinus lambertiana* or *Pseudotsuga menziesii*

X_6 = *Castanopsis sempervirens* or *Prunus emarginata*

X_7 = *Quercus kelloggii*

X_8 = *Pyrola picta*, *Trientalis latifolia*, or *Asarum* spp.

X_9 = *Chimaphila umbellata* var. *occidentalis*, *Pterospora andromedea*, or *Smilacina* spp.

X_{10} = *Pinus ponderosa*

X_{11} = *Ceanothus prostratus*

X_{12} = (elevation)^2

X_{13} = (Dunning's site index)^2 (elevation)

X_{14} = (Dunning's site index)^2 (elevation)^2

AREA 2 (COLUSA, GLENN, LAKE, AND WESTERN TEHAMA COUNTIES)

$$\text{Relative stocking capacity} = \frac{1}{NSDI}(358 + 209X_1 - 44X_2 - 37X_3 + 49X_4 - 98X_5 - 114X_6 - 82X_7 - 55X_8)$$

When: $NSDI$ = normal stand density index

X_1 = stand basal area $\geq$ 50 percent true fir

X_2 = soil depth $\leq$ 18 inches (45.7 cm) deep

X_3 = *Arctostaphylos canescens*

X_4 = *Rosa gymnocarpa*

X_5 = *Phlox speciosa* ssp. *occidentalis*

X_6 = *Arctostaphylos manzanita* or *A. viscida*

X_7 = *Ceanothus cordulatus* or *C. integerrimus*

X_8 = *Pinus sabiniana*, *Quercus garryana*, *Q. garryana* var. *breweri*, or *Q. dumosa*

AREA 3 (MODOC, LASSEN, EASTERN PLUMAS, EASTERN SIERRA, EASTERN NEVADA, EASTERN PLACER, AND EASTERN EL DORADO COUNTIES)

$$\text{Relative stocking capacity} = \frac{1}{NSDI}(318 - 55x_1 + 74x_2 - 47x_3 + 86x_4 - 44x_5 - 61x_6 + 42x_7 + 63x_8 - 59x_9 - 99x_{10} - 44x_{11} - 77x_{12} - 115x_{13} - 35x_{14})$$

When: *NSDI* = normal stand density index

x_1 = soil depth $\leq$ 18 inches (45.7 cm)

x_2 = *Abies magnifica*

x_3 = *Cercocarpus ledifolius* or *C. betuloides*

x_4 = *Symphoricarpos* spp.

x_5 = *Ribes cereum*, *R. inebrians*, or *R. roezlii*

x_6 = *Bromus tectorum* or *Stipa comata*

x_7 = *Achillea lanulosa*

x_8 = *Osmorhiza chilensis*, *Smilacina* spp., *Chimaphila umbellata* var. *occidentalis*, *Pterospora andromedea*, *Pyrola picta*, or *P. Picta* forma *aphylla*

x_9 = *Erysimum perenne* or *E. capitatum*

x_{10} = *Lomatium nudicaule* or *L. plummerae*

x_{11} = *Balsamorhiza* spp.

x_{12} = *Potentilla* spp.

x_{13} = *Calyptridium umbellatum*, *Linanthus ciliatus*, or *L. nuttallii*

x_{14} = *Agoseris heterophylla* or *A. retrorsa*

AREA 4 (YUBA, WESTERN SIERRA, WESTERN NEVADA, WESTERN PLACER, AND WESTERN EL DORADO COUNTIES)

$$\text{Relative stocking capacity} = \frac{1}{NSDI}(171 + X_1 - 142X_2 - 54X_3 - 105X_4 - 109X_5 + 127X_6 - 153X_7 + 99X_8 - 109X_9 + 0.0156X_{10})$$

When: $NSDI$ = normal stand density index

X_1 = U.T.M. grid distance north in 1000 meters minus 4200

X_2 = soil depth $\leq$ 18 inches (45.7 cm)

X_3 = *Arctostaphylos viscida*

X_4 = *Ceanothus cuneatus*

X_5 = *Rubus leucodermis*

X_6 = *Goodyera oblongifolia*

X_7 = *Polygala cornuta*

X_8 = *Viola lobata*

X_9 = *Sitanion hystrix*

X_{10} = (Dunning's site index) (elevation)

AREA 5 (AMADOR, CALAVERAS, TUOLUMNE, MARIPOSA, MADERA, FRESNO, TULARE, AND KERN COUNTIES)

$$\text{Relative stocking capacity} = \frac{1}{NSDI}(328 + 267x_1 - 112x_2 + 92x_3 + 161x_4 + 194x_5 - 91x_6)$$

When: $NSDI$ = normal stand density index

x_1 = *Pinus monticola*

x_2 = *Umbellularia californica*, *Quercus douglasii*, *Quercus garryana* var. *semota*, *Ceanothus cuneatus*, *Cercocarpus betuloides*, *C. ledifolius*, *Rhamnus crocea* ssp. *ilicifolia*, *Chrysothamnus* spp., *Garrya fremontii* or *Pinus sabiniana*

x_3 = *Pterospora andromedea*

x_4 = *Chimaphila menziesii*, *C. umbellata* var. *occidentalis*, *Pyrola picta*, *P. picta* forma *aphylla*, *Adenocaulon bicolor*, *Goodyera oblongifolia*, *Viola lobata*, *Disporum* spp., or *Smilacina* spp.

x_5 = *Pedicularis semibarbata*

x_6 = *Sitanion hystrix*

USING THE EQUATIONS

To use the equations, first search the general area to determine which indicator plants are present. Search thoroughly to find plants that are typically scattered--pinedrops, for example. Ignore plants growing on microsites such as springs, rock outcrops, or skid roads; count all others even if scarce. Also count indicator tree species that have been removed through disturbance when this is known.

RELIABILITY OF THE EQUATIONS

The relative stocking capacity equations are fractions. In each case, the numerator of the fraction is an equation which predicts what stand density index the site will support. The denominator of the fraction, the normal stand density index for the site, is derived from a normal yield table. The data in table 1 describe the reliability of the stand density index prediction equations--the numerators of the fractions.

The equations accounted for between 54 and 77 percent of the variation in stand density index capacity (coefficient of determination, table 1), and the standard error of estimate ranged from 67 to 132 stand density index points when fitted to the basic data by stepwise regression.

The equations were also tested against field data not used in the analysis. They proved as reliable in this independent test as they had in the original analysis. Predicted values were not significantly higher or lower than the measured values. The small amount of bias that did occur--21 stand density index points in area 2--was probably an accident of sampling.

Table 1.--*Reliability of equations for predicting stocking capacity for five geographic areas in California*

Reliability indicators	Area				
	1	2	3	4	5
Basic data:					
Number of plots to develop equation	97	81	84	88	90
Coefficient of determination (R^2)	0.77	0.58	0.68	0.69	0.54
Standard error of estimate[1/]	67	88	85	109	132
Independent test:					
Number of plots	70	27	72	27	37
Standard deviation of residuals[1/]	70	86	87	86	90
Amount by which estimated mean stand density index differed from actual[1/]	+6	+21	+8	+14	+6

[1/] Values are stand density index points.

PLANT NAMES[3/]

Scientific Name	Common Name
Abies concolor (Gord. & Glend.) Lindl.	white fir
Abies magnifica A. Murr.	California red fir
Achillea lanulosa Nutt.	yarrow
Adenocaulon bicolor Hook.	trail plant
Agoseris heterophylla (Nutt.) Greene.	mountain dandelion
Agoseris retrorsa (Benth.) Greene.	mountain dandelion
Arctostaphylos canescens Estw.	hoary manzanita
Arctostaphylos manzanita Parry.	Parry manzanita
Arctostaphylos viscida Parry.	whiteleaf manzanita
Asarum spp. L.	wild ginger
Balsamorhiza spp. Nutt.	balsam root
Bromus tectorum L.	cheat grass
Calyptridium umbellatum (Torr.) Greene.	pussy paws
Castanopsis sempervirens (Kell.) Dudl.	bush chinquapin
Ceanothus cordulatus Kell.	mountain whitethorn
Ceanothus cuneatus (Hook.) Nutt.	buck brush
Ceanothus integerrimus H. & A.	deer brush
Ceanothus lemmonii Parry.	Lemmon ceanothus
Ceanothus prostratus Benth.	squaw carpet
Cercis occidentalis Torr. ex Gray.	redbud
Cercocarpus betuloides Nutt. ex T. & G.	birch-leaf mountain-mahogany
Cercocarpus ledifolius Nutt.	curl-leaf mountain-mahogany
Chimaphila menziesii (R. BR. ex D. Don) Spreng.	pipsissewa
Chimaphila umbellata (L.) Barton var. *occidentalis* (Rydb.) Blake.	prince's pine
Chrysothamnus spp. Nutt.	rabbit-brush
Disporum spp. Salisb.	fairy bells
Erysimum capitatum (Dougl.) Greene.	wallflower
Erysimum perenne (Wats. ex Cov.) Abrams.	wallflower
Garrya fremontii Torr.	silk-tassel bush
Goodyera oblongifolia Raf.	rattlesnake-plantain
Linanthus ciliatus (Benth.) Greene.	linanthus
Linanthus nuttallii (Gray) Greene ex Mlkn.	linanthus
Lomatium nudicaule (Pursh) Coult. & Rose.	hog-fennel
Lomatium plummerae (Coult. & Rose) Coult. & Rose.	hog-fennel
Osmorhiza chilensis H. & A.	sweet-cicely
Pedicularis semibarbata Gray.	lousewart
Phlox speciosa Pursh ssp. *occidentalis* (Durand) Wherry.	phlox
Pinus contorta Dougl.	lodgepole pine
Pinus lambertiana Dougl.	sugar pine
Pinus monticola Dougl.	western white pine
Pinus ponderosa Laws.	ponderosa pine
Pinus sabiniana Dougl.	Digger pine

[3/] Names of trees according to Little (1953); scientific names of grasses, herbs, and shrubs, Munz and Keck (1970).

Polygala cornuta Kell.	milkwort
Potentilla spp. L.	cinquefoil
Prunus emarginata (Dougl.) Walp.	bitter cherry
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Pterospora andromedea Nutt.	pinedrops
Pyrola picta Sm.	shinleaf
Pyrola picta forma *aphylla* (Sm.) Camp.	leafless pyrola
Quercus douglasii Hook & Arn.	blue oak
Quercus dumosa Nutt.	California scrub oak
Quercus garryana Dougl.	Oregon white oak
Quercus garryana Dougl. var. *breweri* (Engelm. in Wats.) Jeps.	Brewer oak
Quercus garryana Dougl. var. *semota* Jeps.	Kaweah oak
Quercus kelloggii Newb.	California black oak
Quercus wislizenii A. DC.	interior live oak
Rhamnus crocea Nutt. in T. & G. ssp. *ilicifolia* (Kell.) C. B. Wolf.	hollyleaf buckthorn
Ribes cereum Dougl.	squaw currant
Ribes inebrians Lindl.	squaw currant
Ribes roezlii Regel.	Sierra gooseberry
Rosa gymnocarpa Nutt. in T. & G.	wood rose
Rubus leucodermis Dougl. ex T. & G.	western raspberry
Sitanion hystrix (Nutt.) J. G. Sm.	bottle-brush squirrel-tail grass
Smilacina spp. Desf.	false solomon's-seal
Stipa comata Trin. & Rupr.	needle and thread grass
Symphoricarpos spp. Duhamel.	snowberry
Trientalis latifolia Hook.	star-flower
Umbellularia californica (Hook. & Arn.) Nutt.	California-laurel
Viola lobata Benth.	pine violet

LITERATURE CITED

Dahms, Walter G.
1964. Gross and net yield tables for lodgepole pine. USDA For. Serv. Res. Pap. PNW-8, 14 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Dunning, Duncan
1942. A site classification for the mixed conifer selection forest of the Sierra Nevada. Calif. For. & Range Exp. Stn. USDA For. Serv. Res. Note 28, 21 p., illus. Berkeley, Calif.

Dunning, Duncan, and L. H. Reineke
1933. Preliminary yield tables for second-growth stands in the California pine region. U.S. Dep. Agric. Tech. Bull. 354, 23 p., illus.

Little, Elbert L., Jr.
1953. Checklist of native and naturalized trees of the United States (including Alaska). U.S. Dep. Agric. Agric. Handb. 41, 472 p.

McArdle, Richard E., W. H. Meyer, and D. Bruce
1961. The yield of Douglas-fir in the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 201 (rev.), 74 p., illus.

MacLean, Colin D., and Charles L. Bolsinger
1973. Estimating productivity on sites with a low stocking capacity. USDA For. Serv. Res. Pap. PNW-152, 18 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Meyer, Walter H.
1961. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agric. Tech. Bull. 630 (rev.), 59 p., illus.

Munz, Philip A., and David D. Keck
1970. A California flora. 1,681 p., illus. Berkeley: Univ. Calif. Press.

Reineke, L. H.
1933. Perfecting a stand density index for even-aged forests. J. Agric. Res. 46: 627-638, illus.

Schumacher, Francis X.
1926. Yield, stand and volume tables for white fir in the California pine region. Calif. Agric. Exp. Stn. Bull. No. 407, 26 p., illus. Univ. Calif., Berkeley.

Schumacher, Francis X.
1930. Yield, stand and volume tables for Douglas-fir in California. Calif. Agric. Exp. Stn. Bull. No. 491, 41 p., illus. Univ. Calif., Berkeley.

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USDA FOREST SERVICE RESEARCH NOTE

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THE MASS DIAGRAM IN TIMBER ACCESS ROAD ANALYSIS

by

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APR 18 1975
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ABSTRACT

Much of the damage caused by timber access roads results from sidecasting of surplus material, a construction practice that has caused stream sedimentation, road failures, and mass soil movements. Recent restrictions on the use of sidecasting require end hauling excess materials, a practice that can increase road construction cost 10 to 30 percent. In the early stages of road planning, the mass diagram is useful in locating the best route to reduce end haul costs and sidecasting. A procedure is presented that will produce a rapid and accurate mass diagram plot from preliminary planning data.

Keywords: Access road system planning, computers.

INTRODUCTION

Mounting pressures on government and private timber managers to reduce the detrimental impact of roads have resulted in a number of modified construction practices. Most notable among these is the end hauling requirement. The purpose of end hauling is to eliminate indiscriminate sidecasting of surplus excavated materials, which are a common source of stream sediments, road embankment failures, and other forms of mass soil movement.

To evaluate the probable impact of end hauling, it would be useful to have an indication of total volumes of excavation and embankment, accumulative volumes, and their locations along the roadway. This information is conveniently provided by the mass diagram and can be provided early in the planning stages of access road location.

Automated analysis of timber access road locations has been discussed in an earlier paper.[1/] The purpose of this paper is to provide a mass diagram and a procedure for implementing the diagram as an addition to General Technical Report PNW-27. This information will be of use to logging and civil engineers, transportation planners, and others involved with the planning, location, and design of timber access roads.

The mass diagram is most often used to determine proper distribution of excavated material, to determine amount and location of waste and borrow materials, and to estimate the costs of borrow and haul of other excavated materials. This paper does not cover details of these procedures.

MASS DIAGRAM

The mass diagram is a plotted curve with the distance along the roadway for the abscissa and the algebraic sums of earthwork quantities for the ordinates. Excavation quantities are considered positive and embankment quantities, negative. The ordinate at the beginning of the curve is zero, and all subsequent ordinates are calculated continuously from that point.

As a brief review, the mass diagram has the following properties:

1. The ordinate at any point on the curve represents the algebraic accumulation of yardage to that point adjusted for shrinkage or swell--excess excavation if above the abscissa and excess embankment if below.

2. The difference in the lengths of any two ordinates is equal to the algebraic difference between excavation and embankment quantities between the two stations at which the ordinates are located.

3. Ascending lines represent excess excavation; descending lines represent excess fill.

4. Convex loops indicate that the haul from excavation to embankment is from left to right; concave loops indicate the haul is in the opposite direction.

EFFECTS OF SIDECASTING

It is difficult to limit fill-slope length or estimate the limits of downslope movement of sidecast excess materials in areas where the sideslope angle approximates the natural angle of repose of excavation or embankment materials. Embankment or sidecast materials tend to run downslope,

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[1/] Doyle Burke. Automated analysis of timber access road alternatives. USDA Forest Service General Technical Report PNW-27, 40 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1974.

seeking their angle of repose and creating sliver fills (fig. 1). Sliver fills are difficult to control, are expensive to construct, and tend to eliminate natural vegetation over the affected downslope area. They open large areas of mineral soil to erosion, are usually difficult to stabilize by seeding and mulching, and are visually unattractive. Unstabilized sliver fills can contribute to various types of soil mass movements associated with road failures.

End hauling has become a common practice to avoid the problems associated with sidecasting roadway materials or constructing sliver fills. It can increase road construction costs by 10 to 30 percent. Depending on the type of excavated material (rock, common, etc.), end hauling is typically specified where side slopes exceed 50 percent. Under current end haul requirements and costs, many roads constructed in past years might not be constructed today, or they would require major relocation to avoid steep side slopes.

Route locations that minimize sidecasting and end hauling are certainly preferred over those that do not. It is best to evaluate these items early in the planning stage.

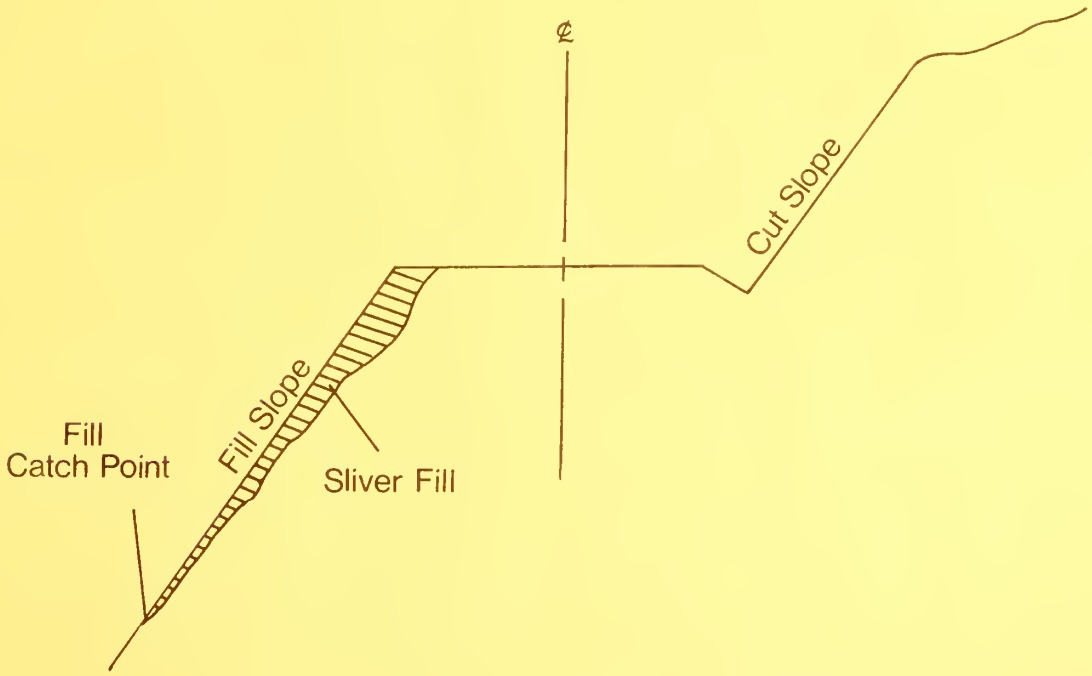

Figure 1.--Diagram of road section with sliver fill.

PLANNING CONSIDERATIONS

Indiscriminate sidecasting of excavated materials and sliver fill construction should be avoided. Ordinarily these factors are treated during final design of the roadway, but in many cases these problems can be reduced by considering the amount and location of materials in the planning process. Indeed, the amount and location of roadway materials may be the deciding factor in selecting among alternate routes.

Figures 2 and 3 illustrate the profile and mass diagram of two possible routes being considered for access to a timber harvest area. Both routes are approximately the same length and traverse locations with similar side slopes. From values shown in table 1, the route alternative of figure 2 would seem more desirable. However, examining the mass diagrams reveals the route alternative in figure 2 has a severe end haul situation, in both length of haul and mass of material. If no further adjustments in horizontal or vertical alinement are practical, the route shown in figure 3 could be more desirable than that of figure 2 if the cost of extra excavation is less expensive.

The decision to end haul should not be taken lightly because of the costs involved. Hence, identification of route locations with minimum end haul problems should be an objective in the planning stages of timber harvest design. The following mass diagram routine provides accurate and rapid plotting, using information preprocessed by the automated timber access road analysis package presented in General Technical Report PNW-27.

Table 1.--*Comparison of design considerations of routes shown in figures 2 and 3*

Design consideration	Route alternatives in:	
	Figure 2	Figure 3
Length (feet)	9,329	9,373
Average side slope (percent)	53	55
Ground profile	Uniform	Moderately broken
Excavation (cubic yard)	27,627	31,169
Embankment (cubic yard)	27,531	33,321
Maximum adverse (percent)	0	-0.7
Maximum favorable (percent)	4.1	7.8
Total clearing	10.89	11.91

NOTE: For both routes:

Subgrade width = 18 feet
Cut slope = 1:1
Fill slope = 1½:1
Extra clearing on cuts = 5 feet
Extra clearing on fills = none.

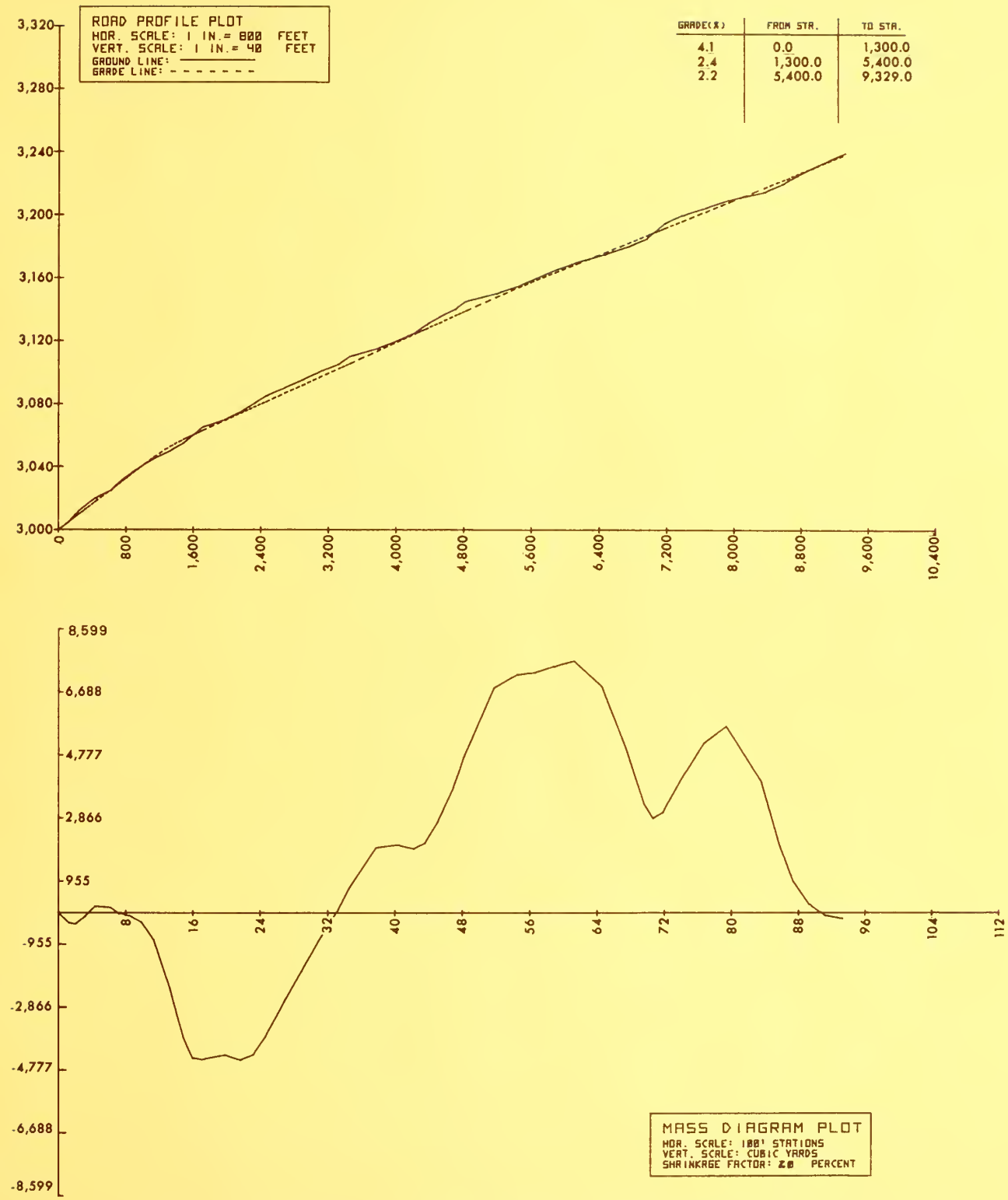

Figure 2.--Road profile and mass diagram plot of road location No. 1.

Figure 3.--Road profile and mass diagram plot of road location No. 2.

GENERAL LOGIC AND SETUP

The generalized logic for the mass diagram routine is illustrated in figure 4.

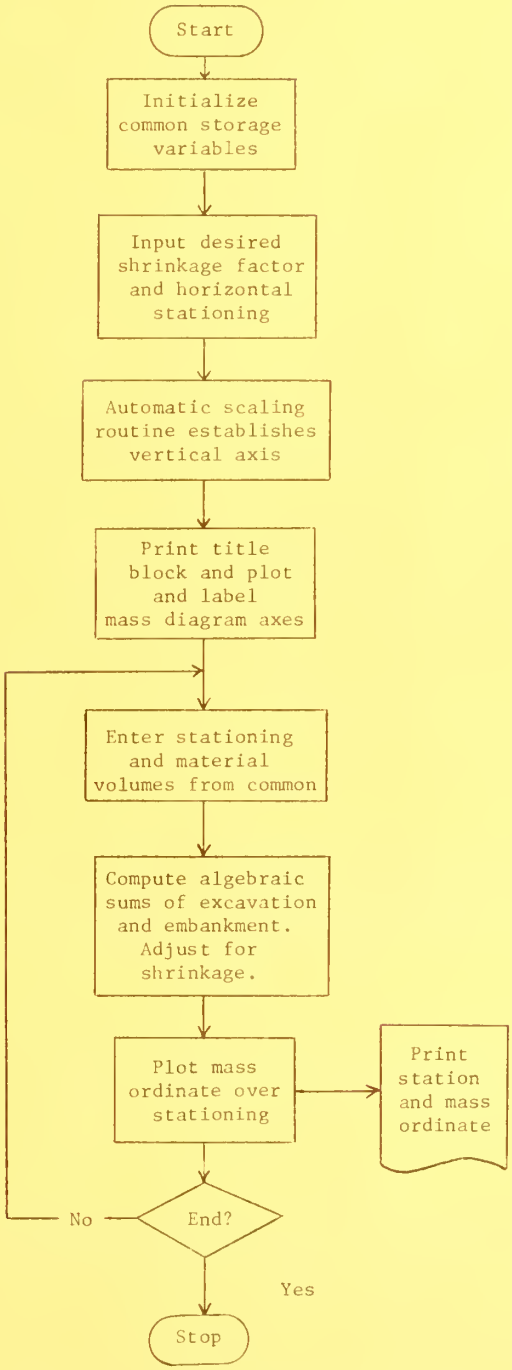
Start
Initialize common storage variables
Input desired shrinkage factor and horizontal stationing
Automatic scaling routine establishes vertical axis
Print title block and plot and label mass diagram axes
Enter stationing and material volumes from common
Compute algebraic sums of excavation and embankment. Adjust for shrinkage.
Plot mass ordinate over stationing
Print station and mass ordinate
End?
No
Yes
Stop

Figure 4.--Mass diagram flow chart.

The method presented in this note was developed for a Hewlett-Packard 9830[2/] calculator system; use of the method requires a knowledge of the system and initializing procedures. The mass diagram program, written in BASIC, should be entered on File 5. Special Function Key 9 should contain *LOAD 5,1,1*. Special Function Key 3 should contain *LOAD 6,1,1,*. All other keys remain unchanged.

Tape files should be organized as follows:

File	Contents
0	Control
1	Keys
2	Road projection routine
3	Horizontal alinement routine
4	Vertical alinement routine
5	Mass diagram routine
6	Earthwork routine

The "timber access road pac" overlay card is shown in figure 5.

[2/] The use of trade, firm, or corporation names in this publication is not an official endorsement or approval by the U.S. Department of Agriculture of any product to the exclusion of others which may be suitable.

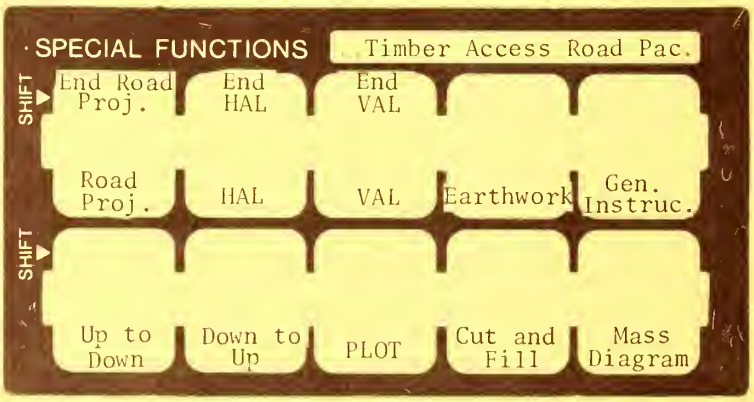

Figure 5.--"Timber access road pac" overlay card.

OPERATING INSTRUCTIONS

1. The mass diagram routine processes earthwork data produced and stored in common by the earthwork routine. A prior earthwork run is required.

2. Press S.F. Key 9.

3. Place paper on the plotter. Make sure plotting area is set for 9 x 14 inches.

4. Enter fill shrinkage, percent, EXECUTE.

5. Enter horizontal distance scale, feet per inch, EXECUTE. (Usually the same horizontal scale as the vertical alinement plot.)

6. The plotter will print the title block, draw and label the axes, and print the stationing and mass ordinates. Typical mass diagram plots are shown in figures 2 and 3.

VARIABLES USED IN THE MASS DIAGRAM ROUTINE, TAPE FILE 5

AS(I,1) = common storage for stationing

AS(I,2) = common storage for ground elevation

B(1) = common storage for station

B(2) = common storage for ground elevation

B(3) = common storage for grade elevation

CØ = counter

GS(I,1) = earthwork stationing

GS(I,2) = excavation yardage

GS(I,3) = embankment yardage

S = shrinkage percent

H = horizontal distance scale

A = counter

Y, Y1, Y2 = sorting variables in autoscaling function

I = counter

V = vertical yardage scale

X = stationing value

```
1 COM AS[ 1ØØ,2],BS[3],CØ,GS[2ØØ,3]
11 DISP "ENTER FILL SHRINKAGE (%)";
21 INPUT S
31 S=(S*Ø.Ø1)+1
41 DISP "ENTER HOR. DISTANCE SCALE";
51 INPUT H
61 REM AUTO Y SCALING ROUTINE
71 Y=Ø
76 A=Ø
81 FOR I=1 TO CØ
86 Y2=Y
91 Y1=(G[I,2]-G[I,3]*S)
1Ø1 Y=Y+Y1
111 IF ABSY>ABSY2 THEN 141
131 GOTO 151
141 IF ABSA>ABSY THEN 151
146 A=ABSY
151 NEXT I
156 V=A/4
161 DEG
171 SCALE Ø,14*H,-4.5*V,4.5*V
181 PLOT 9*H,-3.5*V
191 LABEL (*)"MASS DIAGRAM PLOT"
2Ø1 LABEL (*,1.1,1.7,Ø,9/14)"HOR. SCALE: 1ØØ' STATIONS"
211 LABEL (*,1.1,1.7,Ø,9/14)"VERT. SCALE: CUBIC YARDS"
221 LABEL (*,1.1,1.7,Ø,9/14)"SHRINKAGE FACTOR:"(S-1)*1ØØ"PERCENT"
231 PLOT 8.8*H,-3.2*V,-2
241 PLOT 12.1*H,-3.2*V,-2
251 PLOT 12.1*H,-4.2*V,-2
261 PLOT 8.8*H,-4.2*V,-2
271 PLOT 8.8*H,-3.2*V,-2
281 PEN
291 XAXIS Ø,H,Ø,14*H
3Ø1 YAXIS Ø,V,-4.5*V,4.5*V
311 FIXED Ø
321 FOR X=H TO 14*H STEP H
331 PLOT X,-V/2.5,-1
341 CPLOT Ø,-Ø.3
351 LABEL (*,1,1.7,9Ø,9/14)X/1ØØ
361 NEXT X
371 FOR Y=-4.5*V TO 4.5*V STEP V
381 PLOT 5Ø,Y,-1
391 CPLOT Ø,-Ø.3
4Ø1 LABEL (*,1,1.7,Ø,9/14)Y
411 NEXT Y
421 Y=Ø
425 PRINT "STATION     ORDINATE (CU.YD.)"
431 FOR I=1 TO CØ
441 X=G[I,1]
451 Y1=(G[I,2]-G[I,3]*S)
461 Y=Y+Y1
471 PLOT X,Y
475 PRINT X,Y
491 NEXT I
5Ø1 PEN
511 STOP
```

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

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GPO 992-288

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· USDA FOREST SERVICE RESEARCH NOTE

3.79 PNW235

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LOG PRICES IN WESTERN WASHINGTON AND NORTHWESTERN OREGON, 1963-73

by

Thomas C. Adams, *Principal Economist*

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ABSTRACT

Average log prices are reported for seven principal timber species of western Washington and northwestern Oregon, for the years 1963-73. For water and inland sales, these prices rose from 86.8 to 232.6 percent over this period; and for export sales, from 361.0 to 732.0 percent.

For comparison, the U.S. wholesale price index during this period rose 43.4 percent for lumber and 125.0 percent for all commodities.

Keywords: Logging economics, economics in wood industry, export/import (forest products).

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Forest industries are of major importance to the economies of western Washington and northwestern Oregon,[1] and the trends of log prices are of interest to economists, business managers, and research workers. This report gives average annual log prices for the seven principal species of this area, compiled from Composite Log Sales Analysis reports made available by the Industrial Forestry Association, Portland, Oregon. These species include Douglas-fir, western hemlock, noble fir, white fir, Sitka spruce, western redcedar, and western white pine. The data are from approximately 1.5 billion board feet of log transactions reported annually to the Industrial Forestry Association. They include only log sales and do not include stumpage sales of standing timber.

Prices shown are for water and inland sales combined and for export sales (sales for export outside the United States). Water sales are those in market areas on towable waters but not identified for export. Inland sales are those in market areas not on towable waters and not identified for export.

These log transactions took place at a variety of locations between stump and mill or between stump and export dock. They represent a composite of log prices from a large number of actual transactions, and such prices have been used for many years to give a general picture of long-term price trends and relationships among the different species and grades.

SIGNIFICANCE OF LOG GRADES

Log grades are defined in the official log scaling and grading rules adopted jointly by the six log scaling and grading bureaus operating from northern California northward to Puget Sound and the Canadian border. These rules were developed in cooperation with forest products industry and various public forestry agencies.

For Douglas-fir, three Peeler grades, a Special Mill grade, and four Sawmill grades are used. Other species generally have one Peeler, one Special Mill, and four Sawmill grades.[2] The No. 4 Sawmill grade was introduced in 1972; it covers logs of less than 6 inches in diameter or of less than 50 board feet net volume and suitable for the manufacture of not less than 33-1/3 percent of the gross volume in merchantable material. In addition, the Industrial Forestry Association reports prices of Utility, Special Cull, and Cull logs, but these are not included in this report.

Originally, Peeler grades were intended to designate logs of high quality most suited for manufacture into veneer for plywood. However, construction-type plywood now uses many logs in the Sawmill grades, and frequently some Peeler grade logs are sawn into lumber. However, the Peeler log grades still generally serve to indicate logs with premium characteristics and, hence, higher values.

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[1] The log-producing area designated as northwestern Oregon here includes all coastal counties in Oregon and counties from the north half of Douglas County to the Columbia River.

[2] Prices shown for the Special Mill grade in the years 1963-68 include an S. F. P. grade (suitable for peeling, or special fir peeler). Since 1969, such logs have been included in the Special Mill grade, which covers logs of peeler quality but smaller than the 24-inch diameter requirement for peeler logs.

LOG PRICES CONTINUE UPWARD TREND

Log prices of all species rose steadily between 1963 and 1972 and sharply in 1973. For example, the average price of No. 3 Douglas-fir Peeler logs, the most common Peeler grade, increased 120.6 percent during this period for water and inland sales, from $83.90 to $185.10 per thousand board feet, Scribner scale (table 1, fig. 1). For export sales, the average price of Peeler grades increased 357.4 percent, from $88.80 to $406.20 per thousand board feet.

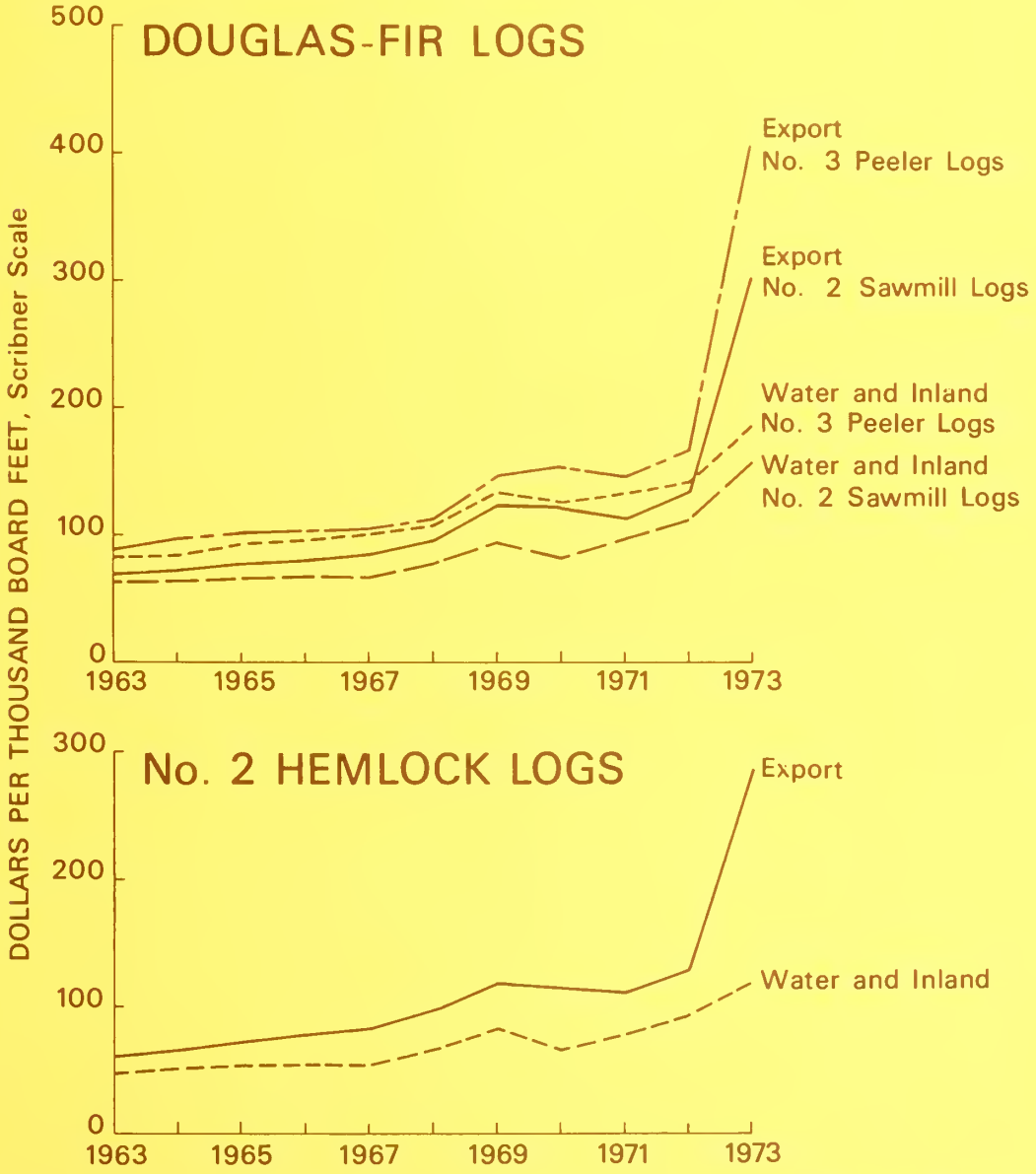

Figure 1.--Average prices for Douglas-fir and western hemlock logs, for export sales, and for water and inland sales, 1963-73.

The average price of No. 2 Douglas-fir Sawmill logs for water and inland sales increased 157.0 percent during the same period, from $61.90 to $159.10 per thousand board feet (table 2). For export sales, the corresponding increase was 332.0 percent, from $69.70 to $301.10.

Western hemlock has the second largest volume of log harvest in this region and the highest volume in export sales. The average price of No. 2 western hemlock logs rose 150.5 percent during 1963-73 in water and inland sales, from $47.50 to $119.00 per thousand board feet (table 3). In export sales, the price rise was 378.2 percent, from $60.10 to $287.40.

For the seven species, the average price increase over this period ranged from 86.8 percent (western white pine) to 232.6 percent (western redcedar) for water and inland sales, and from 361.0 percent (Douglas-fir Sawmill logs) to 732.0 percent (noble fir) for export sales (tables 1-8).

In comparison, the U.S. Bureau of Labor Statistics' wholesale price index for the same period rose 43.4 percent for all commodities and 125.0 percent for lumber alone.

EXPORT LOG SALES

Sales classified as export sales include those identified for export, whether the transaction takes place at an initial scaling point, or at some intermediate point before final delivery alongside ship. Since the 4th quarter of 1970, the relatively few f.a.s. (free alongside ship) invoices have not been included in these reports.

In nearly all cases, export logs show higher values than the same grades for domestic use as reported in water and inland sales. In the past, this has been attributed chiefly to the general requirement that export logs be mostly free of defect and with smaller knots than in domestic sales, and to the extra handling involved in rebucking, rescaling, and assembly of logs for specific export orders by log dealers and export trading companies. Another possible explanation has been the need to offer a higher price to divert logs from established and more stable domestic markets.

The sharp rise in export log prices in 1973 is more than can be explained by the above reasons. It is likely associated with such things as: (1) voluntary agreements of the Japanese to limit log imports coupled with a strong 1972-73 demand for housing in Japan, the principal export log market, (2) the 1971-73 United States price control effort to hold down domestic prices, (3) the restriction made in October 1973 against export of logs in new Federal timber sales from Federal lands west of the 100th meridian in the contiguous 48 States (except for species and quantities found to be surplus to domestic needs), (4) fear that direct controls or antisubstitution measures might reduce export of logs from private lands, (5) the higher relative value apparently placed on lumber and wood products in the Japanese economy, and (6) international monetary revaluations, which made prices in Japanese currency equivalent to significantly higher prices in dollars.

Table 1.--Douglas-fir Peeler log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
No. 1 Peeler:			
1963	111.30	135.00	111.40
1964	114.80	123.90	114.80
1965	121.80	140.30	122.40
1966	125.70	142.00	127.60
1967	123.50	155.80	137.90
1968	143.30	155.60	149.40
1969	162.60	166.80	164.50
1970	157.60	188.90	180.30
1971	159.30	185.40	173.20
1972	195.10	214.30	205.90
1973	239.40	651.50	582.10
No. 2 Peeler:			
1963	99.90	--	99.90
1964	102.20	112.50	102.30
1965	109.40	117.50	109.50
1966	114.00	128.30	114.90
1967	117.60	133.10	122.30
1968	125.50	135.40	128.60
1969	149.80	146.80	148.60
1970	143.50	167.90	156.00
1971	147.80	163.00	153.40
1972	163.60	187.50	174.40
1973	211.10	514.80	396.80
No. 3 Peeler:			
1963	83.90	88.80	84.00
1964	84.40	97.40	85.00
1965	92.50	100.70	92.80
1966	96.80	103.40	97.70
1967	100.70	105.70	103.00
1968	108.80	111.20	110.20
1969	133.60	145.20	137.40
1970	124.70	152.60	136.80
1971	131.50	145.10	135.30
1972	140.90	165.90	149.20
1973	185.10	406.20	270.70
Special Mill:			
1963	71.20	75.00	72.00
1964	73.40	82.20	74.50
1965	78.50	89.10	80.30
1966	83.60	89.90	86.10
1967	84.30	94.20	89.90
1968	96.90	103.50	100.80
1969	124.40	136.40	132.10
1970	106.60	132.30	125.00
1971	115.20	125.60	119.30
1972	130.00	143.00	135.70
1973	175.20	338.90	276.50
Average:			
1963	86.00	76.00	85.20
1964	85.80	86.20	85.90
1965	93.90	93.90	93.90
1966	97.90	96.40	97.50
1967	103.80	108.50	105.90
1968	109.80	112.40	111.00
1969	134.40	140.90	137.70
1970	122.30	145.50	136.60
1971	127.60	141.50	132.60
1972	140.60	160.50	148.90
1973	186.00	427.20	320.40

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 2.--Douglas-fir Sawmill log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
No. 1 Sawmill:			
1963	67.30	--	67.30
1964	68.30	--	68.30
1965	72.10	78.30	72.20
1966	73.20	72.00	73.20
1967	70.80	93.90	72.70
1968	89.20	99.60	90.90
1969	106.80	116.90	109.70
1970	100.80	127.70	106.80
1971	109.20	122.00	110.60
1972	127.30	169.30	139.40
1973	188.40	326.80	226.70
No. 2 Sawmill:			
1963	61.90	69.70	62.70
1964	63.50	71.70	64.90
1965	66.60	78.70	67.90
1966	67.60	80.50	70.00
1967	67.80	85.00	73.40
1968	79.10	97.90	87.50
1969	94.90	123.80	107.80
1970	82.20	120.90	100.70
1971	96.40	112.30	100.10
1972	112.40	133.50	119.10
1973	159.10	301.10	207.00
No. 3 Sawmill:			
1963	50.60	58.20	52.70
1964	52.10	60.10	53.40
1965	54.20	60.70	55.40
1966	54.90	63.90	56.10
1967	54.60	70.70	57.90
1968	63.90	88.00	70.60
1969	76.90	112.70	86.70
1970	63.20	95.10	69.40
1971	73.30	94.50	75.00
1972	87.10	112.40	90.90
1973	125.10	218.40	138.60
No. 4 Sawmill:			
1972	97.90	100.30	94.70
1973	119.20	106.30	118.30
Mixed grade:			
1963	--	--	--
1964	60.40	78.80	64.60
1965	66.60	81.40	69.70
1966	71.00	78.20	74.70
1967	72.30	80.40	78.40
1968	81.80	96.40	86.60
1969	88.00	124.00	95.40
1970	70.90	118.30	86.00
1971	83.60	119.00	87.90
1972	103.90	111.20	104.90
1973	126.40	276.60	156.80
Ungraded:			
1963	51.20	54.30	52.00
1964	38.30	58.40	39.50
1965	44.20	51.10	44.20
1966	49.20	78.30	50.50
1967	46.30	68.30	53.10
1968	63.40	71.40	66.90
1969	79.60	88.60	81.80
1970	74.30	84.70	76.20
1971	71.70	96.40	73.40
1972	102.80	85.60	101.80
1973	132.00	300.50	136.10
Average:			
1963	57.90	61.60	58.50
1964	57.70	68.50	59.50
1965	61.50	72.50	63.00
1966	62.30	77.10	65.00
1967	61.80	80.00	68.90
1968	75.00	93.20	82.00
1969	88.10	122.40	98.70
1970	73.50	116.90	89.30
1971	86.20	111.50	90.20
1972	86.80	125.40	95.10
1973	137.30	284.00	172.30

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 3.--Western hemlock log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
Peeler log:			
1963	64.20	72.60	66.20
1964	66.90	80.10	72.20
1965	77.20	84.80	81.00
1966	81.80	84.30	83.70
1967	82.90	96.80	94.70
1968	93.30	110.20	109.00
1969	117.70	143.20	141.30
1970	111.50	144.80	142.20
1971	110.20	139.30	134.30
1972	122.20	169.90	162.80
1973	167.80	422.80	410.80
Special Mill:			
1963	57.40	60.70	60.10
1964	88.00	71.90	76.40
1965	65.00	84.80	78.20
1966	66.10	80.80	79.20
1967	69.10	88.00	87.20
1968	89.40	101.00	100.40
1969	105.10	128.80	126.80
1970	87.70	127.40	124.90
1971	95.00	121.60	116.20
1972	111.50	141.10	135.20
1973	144.50	326.90	313.10
No. 1:			
1963	59.00	67.50	62.30
1964	62.30	75.60	68.80
1965	71.60	78.80	76.10
1966	74.80	87.70	84.60
1967	75.30	91.60	90.00
1968	86.80	105.60	104.40
1969	109.90	138.90	134.90
1970	98.30	139.00	133.70
1971	106.80	132.10	126.00
1972	116.60	154.60	143.90
1973	149.60	379.40	349.20
No. 2:			
1963	47.50	60.10	51.90
1964	50.10	64.60	55.20
1965	52.70	71.00	63.10
1966	53.30	77.80	66.50
1967	53.30	81.70	75.50
1968	65.60	96.00	89.90
1969	81.70	119.30	110.30
1970	66.20	116.40	102.90
1971	77.20	110.50	91.90
1972	92.20	128.60	111.20
1973	119.00	287.40	238.30
No. 3:			
1963	40.30	56.20	42.70
1964	41.90	56.70	44.30
1965	44.40	62.60	50.40
1966	44.60	68.90	49.60
1967	45.20	71.70	57.30
1968	55.20	87.20	74.30
1969	70.80	112.10	97.20
1970	56.00	104.70	81.10
1971	64.50	95.80	71.30
1972	76.10	114.40	92.90
1973	107.70	253.40	187.90
No. 4:			
1972	79.70	--	79.70
1973	92.20	172.60	101.00
Mixed grade:			
1963	--	--	--
1964	46.70	61.70	56.60
1965	48.20	67.60	59.40
1966	48.30	72.60	62.50
1967	50.60	76.20	67.70
1968	63.40	89.70	81.00
1969	75.50	113.00	87.90
1970	61.00	99.60	69.50
1971	69.80	96.30	79.80
1972	80.50	112.60	90.70
1973	104.20	218.10	167.60
Ungraded:			
1963	44.70	54.90	50.60
1964	41.00	53.40	45.80
1965	42.80	63.30	48.50
1966	44.30	60.50	48.60
1967	45.00	66.70	52.10
1968	55.80	81.00	63.90
1969	68.10	89.80	70.70
1970	54.10	117.60	58.10
1971	64.90	109.50	75.10
1972	80.40	83.10	80.50
1973	118.10	232.10	119.20
Average:			
1963	46.90	56.80	51.60
1964	47.60	62.20	55.20
1965	49.30	70.00	60.40
1966	49.80	76.00	64.20
1967	49.20	80.60	70.30
1968	62.20	96.00	87.60
1969	78.40	122.40	108.80
1970	63.30	120.80	99.90
1971	72.50	111.70	89.50
1972	85.50	129.10	105.60
1973	112.90	286.00	225.70

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 4.--Noble fir log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
Peeler log:			
1963	66.60	96.80	94.80
1964	78.70	103.60	102.20
1965	106.40	133.90	132.40
1966	102.00	145.50	144.90
1967	114.00	150.20	149.90
1968	153.90	168.00	167.50
1969	153.50	191.30	190.20
1970	114.30	192.20	191.30
1971	137.00	196.30	192.70
1972	149.50	244.00	236.20
1973	160.20	931.90	901.80
Special Mill:			
1963	53.00	73.30	72.90
1964	68.70	78.60	78.20
1965	84.30	102.50	101.60
1966	83.30	116.40	115.50
1967	85.80	124.20	123.40
1968	104.10	136.60	135.90
1969	99.30	164.30	162.90
1970	98.70	155.30	153.20
1971	104.60	158.50	146.90
1972	118.80	186.30	170.30
1973	140.90	549.90	488.00
No. 1:			
1963	57.60	87.90	86.70
1964	77.50	94.10	93.50
1965	92.30	122.60	120.90
1966	82.80	131.70	130.50
1967	86.70	143.20	142.50
1968	130.20	157.90	156.20
1969	141.40	181.90	178.40
1970	92.80	182.30	175.00
1971	116.70	190.20	172.10
1972	128.40	233.70	205.10
1973	143.30	818.60	751.60
No. 2:			
1963	50.80	65.50	62.10
1964	50.50	69.80	62.90
1965	53.90	88.40	84.00
1966	63.30	96.40	94.60
1967	67.40	101.40	100.30
1968	84.90	113.30	110.90
1969	101.60	128.70	124.40
1970	70.90	120.60	109.30
1971	84.90	124.60	110.80
1972	99.50	152.00	131.60
1973	132.60	343.20	256.80

Log grade and year	Water and inland sales	Export sales	All sales
No. 3:			
1963	43.00	57.60	50.30
1964	43.60	66.80	57.70
1965	45.80	72.00	64.10
1966	46.10	75.20	69.70
1967	47.40	75.70	73.30
1968	69.50	82.10	80.00
1969	72.70	100.90	92.30
1970	62.70	101.80	75.30
1971	69.90	98.20	79.20
1972	81.40	121.80	100.40
1973	115.80	235.40	180.60
No. 4:			
1972	94.10	--	94.10
1973	97.10	111.20	99.90
Mixed grade:			
1963	--	--	--
1964	60.70	64.10	63.70
1965	62.00	87.00	81.90
1966	46.70	85.40	75.40
1967	51.40	89.50	77.50
1968	71.00	99.10	97.30
1969	84.10	128.20	106.20
1970	73.00	102.10	85.20
1971	86.30	89.80	87.20
1972	77.20	146.40	116.60
1973	113.10	239.20	135.20
Ungraded:			
1963	51.20	57.60	55.80
1964	35.80	--	35.80
1965	43.70	94.10	82.40
1966	40.00	--	40.00
1967	41.50	38.10	41.50
1968	49.80	--	49.80
1969	48.80	--	48.80
1970	59.10	--	59.10
1971	87.80	--	87.80
1972	50.70	--	50.70
1973	172.50	--	172.50
Average:			
1963	51.50	74.90	71.00
1964	54.60	84.80	80.50
1965	63.20	105.30	100.60
1966	57.70	116.20	112.40
1967	48.00	123.90	114.20
1968	97.80	137.40	135.00
1969	95.60	160.20	151.90
1970	71.70	161.10	143.40
1971	93.80	165.50	145.70
1972	102.10	190.80	164.10
1973	128.20	623.20	465.10

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 5.--White fir log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
Peeler log:			
1963	64.90	70.90	65.60
1964	66.60	81.60	70.60
1965	76.10	84.80	79.60
1966	79.30	91.70	88.60
1967	81.00	95.60	92.70
1968	87.10	107.00	104.90
1969	111.90	142.10	139.70
1970	113.40	138.20	134.40
1971	105.90	137.20	131.30
1972	118.90	183.00	172.80
1973	156.40	411.40	398.60
Special Mill:			
1963	58.90	61.60	60.20
1964	59.70	74.00	66.90
1965	66.40	78.40	73.90
1966	68.40	82.20	79.40
1967	68.00	85.20	82.60
1968	79.90	97.80	97.20
1969	98.60	127.30	124.50
1970	101.20	120.10	118.10
1971	95.60	121.40	117.10
1972	107.80	152.80	144.70
1973	141.90	324.80	314.40
No. 1:			
1963	59.40	66.50	61.00
1964	62.90	76.00	67.60
1965	71.40	80.40	76.30
1966	74.30	87.60	83.60
1967	74.70	90.40	87.90
1968	86.10	101.20	100.00
1969	99.50	133.20	126.10
1970	104.80	130.30	125.00
1971	99.70	124.30	120.00
1972	115.80	166.60	153.10
1973	142.60	357.70	338.90
No. 2:			
1963	51.00	61.10	53.00
1964	52.60	62.40	54.40
1965	55.40	72.40	62.70
1966	56.50	78.60	70.30
1967	53.00	81.90	76.20
1968	63.80	94.40	90.10
1969	72.60	116.80	102.60
1970	74.40	109.80	101.00
1971	79.90	109.50	101.90
1972	98.20	138.70	128.80
1973	129.20	280.00	255.50
No. 3:			
1963	41.20	57.00	45.40
1964	42.90	57.10	44.30
1965	45.40	65.10	49.80
1966	44.80	71.30	53.90
1967	47.00	74.80	60.30
1968	53.10	85.80	72.20
1969	61.90	109.70	85.90
1970	59.10	99.20	76.30
1971	65.60	90.60	79.00
1972	84.80	119.50	110.90
1973	106.20	239.60	207.70
No. 4:			
1972	87.50	80.20	85.80
1973	92.00	132.80	99.10
Mixed grade:			
1963	--	--	--
1964	46.80	60.20	54.70
1965	60.40	70.40	66.20
1966	55.00	79.00	71.70
1967	53.60	82.00	75.00
1968	63.70	91.40	81.00
1969	79.00	121.20	95.60
1970	64.50	91.40	76.00
1971	76.20	103.20	93.80
1972	80.40	121.20	100.30
1973	95.20	229.10	173.40
Ungraded:			
1963	41.60	55.20	48.30
1964	38.50	54.30	44.00
1965	42.60	65.70	46.90
1966	42.60	59.80	50.60
1967	44.40	68.70	49.80
1968	51.70	86.70	59.10
1969	69.50	120.90	70.40
1970	44.00	80.40	44.50
1971	71.40	47.40	69.30
1972	74.10	79.60	74.20
1973	122.30	285.20	122.70
Average:			
1963	51.10	58.40	53.40
1964	50.90	63.10	55.30
1965	56.20	73.10	63.90
1966	55.20	80.00	71.10
1967	53.10	83.90	75.60
1968	61.20	95.10	87.20
1969	75.40	124.10	108.00
1970	71.70	114.80	100.90
1971	78.70	112.50	101.90
1972	88.90	145.40	126.40
1973	112.00	299.10	256.00

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 6.--Sitka spruce log prices, western Washington and northwestern, Oregon. 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
Select log:			
1963	88.40	99.20	91.20
1964	99.30	121.60	113.00
1965	138.30	140.80	140.20
1966	136.30	147.00	144.80
1967	147.60	151.00	150.50
1968	166.00	154.70	156.00
1969	244.40	229.20	229.80
1970	115.60	214.90	192.80
1971	161.10	204.80	203.90
1972	221.90	215.90	216.40
1973	480.80	1,072.00	1,046.20
Special Mill:			
1963	--	--	--
1964	--	--	--
1965	--	--	--
1966	66.10	92.90	88.10
1967	67.60	109.30	92.30
1968	--	102.00	102.00
1969	119.50	181.40	175.50
1970	114.70	165.50	164.60
1971	85.80	168.20	162.80
1972	107.10	174.00	164.30
1973	388.60	532.70	530.00
No. 1:			
1963	71.30	83.20	74.90
1964	76.90	103.80	92.80
1965	107.70	121.90	118.10
1966	101.70	132.90	127.90
1967	106.10	141.40	135.30
1968	126.80	163.60	157.80
1969	194.80	216.90	214.90
1970	167.70	201.40	199.80
1971	117.40	193.10	188.50
1972	134.00	208.80	200.90
1973	324.50	935.80	906.70
No. 2:			
1963	51.70	64.70	55.20
1964	57.70	76.20	65.00
1965	71.70	80.70	77.30
1966	62.40	99.90	87.40
1967	64.20	95.50	89.50
1968	77.90	118.50	111.50
1969	124.00	156.50	152.20
1970	89.20	136.60	130.60
1971	78.30	123.60	104.60
1972	93.40	138.70	116.30
1973	146.80	403.60	327.30
No. 3:			
1963	41.90	48.10	42.80
1964	43.10	53.20	45.70
1965	46.30	47.10	46.60
1966	46.50	63.40	49.90
1967	44.30	67.10	52.10
1968	49.30	85.70	69.80
1969	74.10	110.60	94.70
1970	59.70	102.80	88.90
1971	59.30	83.90	65.80
1972	69.10	98.40	74.50
1973	97.60	261.80	138.60
No. 4:			
1972	--	--	--
1973	98.20	--	98.20
Mixed grade:			
1963	--	--	--
1964	50.30	68.90	60.10
1965	55.00	84.50	64.40
1966	67.60	79.00	73.40
1967	61.00	97.20	77.20
1968	79.50	100.50	86.60
1969	102.90	165.00	120.90
1970	88.80	123.60	98.90
1971	89.80	103.70	90.90
1972	96.70	109.60	99.20
1973	154.80	355.00	230.70
Ungraded:			
1963	51.20	51.40	51.20
1964	33.60	47.70	40.50
1965	43.80	72.70	46.70
1966	46.10	65.50	50.40
1967	44.00	46.70	44.20
1968	57.00	102.60	66.40
1969	85.10	293.40	87.20
1970	51.00	49.60	51.00
1971	63.10	--	63.10
1972	73.70	--	73.70
1973	115.10	117.10	115.10
Average:			
1963	56.00	70.00	59.30
1964	58.10	83.40	69.00
1965	66.10	94.90	81.20
1966	64.40	107.30	89.60
1967	62.00	107.00	92.60
1968	82.40	129.10	115.60
1969	106.40	175.30	152.80
1970	91.40	162.50	139.00
1971	87.90	150.60	103.20
1972	94.60	156.00	116.30
1973	152.00	529.50	349.70

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 7.--Western redcedar log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
No. 1:			
1963	74.30	83.00	74.50
1964	76.60	84.80	76.80
1965	84.20	97.00	85.10
1966	87.10	101.60	88.90
1967	81.60	112.60	87.70
1968	98.00	127.20	102.60
1969	143.70	164.40	146.60
1970	128.30	170.20	141.40
1971	136.50	170.00	142.40
1972	161.80	180.50	166.40
1973	241.60	471.50	296.60
No. 2:			
1963	51.50	64.30	51.80
1964	54.10	71.70	54.60
1965	57.50	77.20	59.00
1966	60.10	82.60	62.50
1967	61.00	85.60	66.50
1968	75.60	102.70	80.80
1969	108.80	139.20	116.30
1970	85.40	144.70	107.20
1971	100.40	140.10	105.40
1972	130.70	156.90	134.70
1973	201.70	399.40	239.50
No. 3:			
1963	41.70	57.30	42.30
1964	45.30	51.00	45.60
1965	45.70	54.60	46.20
1966	43.60	61.90	44.90
1967	46.30	65.30	51.40
1968	54.90	70.80	57.70
1969	72.50	104.80	81.40
1970	57.70	100.40	68.10
1971	66.30	89.90	67.90
1972	86.90	103.60	89.10
1973	137.50	257.40	159.80
No. 4:			
1972	76.10	66.70	73.80
1973	95.30	103.50	96.00
Mixed grade:			
1963	--	--	--
1964	50.40	43.80	49.50
1965	47.80	62.70	48.40
1966	44.70	64.40	46.70
1967	47.90	62.80	49.90
1968	61.70	73.20	64.20
1969	80.20	95.70	83.10
1970	58.10	102.40	59.60
1971	63.50	92.80	63.90
1972	78.60	92.70	80.00
1973	172.30	230.40	129.70
Ungraded:			
1963	47.40	55.70	47.50
1964	46.00	44.80	46.00
1965	48.50	61.00	48.50
1966	54.40	61.20	54.50
1967	43.80	59.60	52.50
1968	55.40	89.00	56.50
1969	84.50	86.90	84.50
1970	69.10	--	69.10
1971	87.00	144.70	92.10
1972	94.80	--	94.80
1973	128.50	84.70	128.30
Average:			
1963	51.80	64.10	52.10
1964	54.10	60.10	54.30
1965	56.20	73.50	57.30
1966	56.40	79.00	58.40
1967	57.60	77.60	62.50
1968	71.20	94.10	75.40
1969	100.00	124.60	105.60
1970	77.90	136.90	94.20
1971	88.50	137.30	93.30
1972	108.90	140.60	113.20
1973	172.30	334.10	202.00

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

Table 8.--Western white pine log prices, western Washington and northwestern Oregon, 1963-73

(Dollars per thousand board feet, Scribner log scale)

Log grade and year	Water and inland sales	Export sales	All sales
Peeler log:			
1963	79.00	--	79.00
1964	73.60	60.30	69.50
1965	89.40	59.40	83.80
1966	77.80	87.30	86.40
1967	84.40	93.30	90.80
1968	108.10	96.10	97.60
1969	101.30	104.20	104.10
1970	85.70	127.80	119.20
1971	89.90	98.80	93.60
1972	94.70	168.00	133.80
1973	190.90	566.00	480.30
Special Mill:			
1963	80.80	--	80.80
1964	58.40	--	58.40
1965	76.90	77.80	76.90
1966	70.30	97.10	93.40
1967	72.10	103.30	91.60
1968	88.20	112.20	108.20
1969	90.00	124.40	118.00
1970	83.10	123.90	111.00
1971	89.10	114.20	96.70
1972	91.30	138.00	122.40
1973	161.90	371.60	320.00
No. 1 Sawmill:			
1963	57.00	56.60	56.80
1964	65.80	54.60	60.20
1965	83.30	66.90	80.80
1966	65.00	80.20	78.20
1967	77.60	83.40	82.30
1968	90.70	77.80	78.80
1969	103.30	105.20	104.80
1970	82.20	107.40	100.50
1971	114.20	83.20	95.70
1972	93.30	153.40	123.20
1973	150.60	446.10	344.80
No. 2 Sawmill:			
1963	49.50	51.90	49.90
1964	55.00	45.70	52.60
1965	62.90	54.80	61.60
1966	56.00	59.00	58.10
1967	57.40	72.90	66.90
1968	68.50	66.20	67.00
1969	76.40	93.40	88.10
1970	69.00	107.50	84.10
1971	68.50	113.80	74.10
1972	74.90	122.20	88.10
1973	104.70	260.10	177.80
No. 3 Sawmill:			
1963	43.50	36.00	43.20
1964	43.00	43.50	43.20
1965	46.60	41.60	45.50
1966	45.40	39.40	41.60
1967	45.40	39.50	43.00
1968	52.20	46.80	48.40
1969	62.80	66.30	64.40
1970	54.90	56.70	55.40
1971	54.10	44.40	52.80
1972	60.20	97.40	64.60
1973	82.60	--	82.60
No. 4 Sawmill:			
1972	64.00	71.30	68.40
1973	82.60	--	82.60
Mixed grade:			
1963	--	--	--
1964	62.80	63.90	63.20
1965	52.00	56.60	52.40
1966	50.10	64.90	59.30
1967	41.40	73.90	55.60
1968	46.40	82.90	55.40
1969	65.50	88.80	68.60
1970	50.60	87.60	64.50
1971	66.80	64.30	66.30
1972	74.10	94.50	74.40
1973	81.20	366.20	96.30
Ungraded:			
1963	42.30	54.80	44.90
1964	42.50	--	42.50
1965	36.60	--	36.60
1966	36.50	--	36.50
1967	46.70	44.90	45.20
1968	58.80	74.00	65.00
1969	69.80	111.20	71.60
1970	60.10	105.20	60.90
1971	64.20	45.70	62.60
1972	70.90	--	70.90
1973	85.00	172.70	86.60
Average:			
1963	48.60	53.50	49.40
1964	49.10	45.20	47.50
1965	54.40	54.60	54.50
1966	42.90	65.70	54.20
1967	52.90	71.00	63.60
1968	53.90	65.50	59.50
1969	69.50	95.60	78.80
1970	60.00	100.30	72.80
1971	67.00	80.90	69.40
1972	74.00	135.70	85.10
1973	90.80	353.20	158.30

Source: Pacific Northwest Forest and Range Experiment Station compilation of regional log values based on composite log sales analyses of Industrial Forestry Association, Portland, Oregon. These prices may reflect costs of towing, sorting, bundling, or other handling, depending on the point of sale in each transaction. Data for 1963 include third and fourth quarters only.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

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GREENHOUSE AND FIELD FERTILIZATION OF THIN-LEAVED HUCKLEBERRY

by

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ABSTRACT

Nitrogen had a greater effect than potassium or phosphorus on thin-leaved huckleberry seedling growth in greenhouse nutrient experiments, with high levels providing the best growth. Fertilization of wild huckleberry fields with ammonium sulfate stimulated vegetative growth, especially when applied at levels of 40 and 160 pounds of nitrogen per acre. Foliar analysis showed that other nutrients were present in adequate concentrations in the field to support this increased vegetative growth.

Keywords: Huckleberry, *Vaccinium membranaceum*, nutrition (- plant physiology).

1/ *Mr. Nelson is a graduate student at Oregon State University.* *The study was funded through cooperative research agreement 16 USC 581 between Oregon State University and the U.S. Forest Service.*

INTRODUCTION

Fields of thin-leaved huckleberry (*Vaccinium membranaceum* Dougl.) constitute an important recreational resource. The fields, however, are shrinking in size, declining in productivity, and being used by increasing numbers of people (Minore 1972). Management plans should be devised for the most popular fields to insure their continuing existence. To date, such plans have been aimed at controlling the activities of berrypickers to minimize site deterioration. Little attention has been directed at huckleberry management, for until recently little was known about the western species of *Vaccinium*. Much more is known about the eastern highbush (*V. corymbosum* L.) and lowbush (*V. angustifolium* Ait.) blueberries.

Fertilization has been used to increase production in cultivated eastern fields for many years. Smith et al. (1946) found that using a complete fertilizer produced more vegetative growth and more and larger berries. Several authors have reported increased yields after using only a nitrogen fertilizer (Trevett 1965a, Bailey et al. 1966, Trevett et al. 1966). Trevett (1965b) found that the time of application of the nitrogen fertilizer had an effect on the response. Application before the shoots emerged caused an increase in stem growth, and application at the time of shoot dieback caused an increase in the fruit bud ratio (number of fruit buds per inch of stem) the following season. Boller (1951), working with eastern *Vaccinium* species in Oregon, found nitrogen to be the only nutrient necessary in fertilization and suggested the use of ammonium sulfate to increase the soil acidity.

The form of nitrogen is important in the eastern species. Cain (1952) found that NH_4-N was absorbed more readily than NO_3-N and that a higher nitrogen concentration was present in the leaves of plants receiving NH_4-N. Townsend (1967), using pot tests, found NH_4-N to be sufficient to maintain growth. In contrast, plants receiving NO_3-N as the only form died within 3 weeks. Plants receiving both forms together grew satisfactorily, but at a rate less than that of plants receiving NH_4-N only. Herath and Eaton (1968) found that the nitrogen concentration in the leaves increased with increasing levels of NH_4-N between 0 and 60 pounds of nitrogen per acre.

Greenhouse tests using nutrient solutions have provided additional information on the nutrition of eastern species of *Vaccinium*. Doehlert and Shive (1936) found that a high level of nitrogen and low levels of phosphorus and potassium resulted in the best vegetative growth and the highest fruit yield. They also found that a low level of nitrogen and a high level of phosphorus resulted in the poorest growth.

Foliar analysis has been used to find normal nutrient ranges and as an indicator of fertilization effects. Bailey et al. (1949) suggested that satisfactory nutrient levels for cultivated blueberries are lower than those of other fruit crops. Satisfactory foliar levels have been proposed (Ballinger and Goldston 1967, Trevett 1972). Generally accepted percentages at the start of the growing season are 1.5 to 2.0 for nitrogen, 0.08 to 0.12 for phosphorus, 0.40 to 0.55 for potassium, 0.40 to 0.65 for calcium, and 0.15 to 0.20 for magnesium. These nutrient levels change throughout the growing season (Bailey et al. 1962, Townsend and Hall 1970). Nitrogen generally declines; phosphorus follows the same trend but has a slight increase at the end of the season; potassium declines until the middle of the season and then increases to nearly the initial level.

Research reported here concerns the nutrient requirements of *V. membranaceum* Dougl. Two general approaches to this problem were used--a field

fertilization study and greenhouse pot experiments. The field study was designed to test the effect of various levels of nitrogen on vegetative growth and berry production. The greenhouse experiments were designed to ascertain the minimum nutrient levels necessary to maintain optimum growth in sand culture and the optimum pH level of the nutrient solution. In addition, a third study was carried out in the greenhouse using soil from the field and fertilizer levels equal to those used in the field to check the fertilizer effect under more optimum growth conditions.

FIELD FERTILIZATION STUDY

Methods

The field study was located in the Sawtooth huckleberry field, Mount Adams Ranger District, Gifford Pinchot National Forest, in southwestern Washington. The field occupies over 2,000 acres of gentle topography, but the area is shrinking due to brush and tree encroachment.

Forty plots of 1/100-acre were marked in a relatively uniform area. Four nitrogen fertilization treatments then were assigned within each of 10 randomized blocks. Treatments were: 0 (control), 10, 40, and 160 pounds of nitrogen per acre. Ammonium sulfate, which is the recommended fertilizer for eastern fields, was used as the source of nitrogen. The fertilizer was spread by hand in October 1972.

Growth data from the fertilizer study were gathered during late August 1973, by collecting 10 individual new shoots from each plot by mechanical sampling. These were selected by running a line with 10 knots at random intervals between the opposite corners of each plot. At each knot, the new shoot nearest the knot was clipped. After its length was measured, each twig was dried in an oven at 70° C for 5 days and weighed.

Foliar analyses were performed on the leaves of plants from both field and greenhouse studies. The leaves of each treatment group were prepared by grinding them through a 40-mesh screen and collecting the ground material in glass vials. Each open vial was placed in an oven at 70° C the afternoon before analysis. Percent nitrogen was determined by the micro-Kjeldahl method (Association of Official Agricultural Chemists 1950). Cations were determined after wet ash digestion (Fiske and Subbarrow 1925). Percent phosphorus was determined colorimetrically, and percent potassium and calcium were determined by flame spectroscopy (Chapman and Pratt 1961).

Results and Discussion

The 1973 huckleberry season was extremely poor. This is attributed to two factors. An extremely cold week in early December, before the bushes were covered with snow, killed many of the buds; and a freeze in mid-June, when the bushes were in bloom, caused heavy flower drop. As there were no berries, no data on the effect of the fertilizer treatments on berry production could be gathered.

All fertilizer treatments produced significantly longer and heavier new growth than the control treatment (table 1). The 40 and 160 pounds of nitrogen per acre produced significantly more growth than did 10 pounds. Although the 160-pound treatment showed slightly better growth than the 40-pound treatment, this difference was not statistically significant. This indicates that 40 pounds of nitrogen per acre produces a response which is nearly equal to the maximum possible response from fertilization. At levels higher than 40 pounds of nitrogen per acre, other factors may override the beneficial effect of nitrogen on huckleberry growth. For example, high levels of fertilization may produce an undesirable response from the competing vegetation, as in eastern fields.

Table 1.--*Average new growth length, ovendry weight, and foliage nutrient concentration of huckleberry bushes after field fertilization treatments*[1/]

Treatment (lb N/acre)	Length[2/]	Weight[2/]	N[2/]	P[3/]	K[3/]	Ca[3/]
	cm	*g*	- - - - - - - - - *Percent* - - - - - - - - -			
0	32.3*a*	1.39*a*	1.76*ab*	0.170*a*	0.91*a*	0.74*a*
10	41.5*b*	1.80*b*	1.71*a*	.167*a*	1.02*a*	.74*a*
40	50.2*c*	2.42*c*	1.80*b*	.160*a*	.86*a*	.68*a*
160	57.7*c*	2.79*c*	1.83*b*	.183*a*	.98*a*	.76*a*

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test.

[2/] Each observation is the average of 10 plots.

[3/] Each observation is the average of 2 plots chosen at random.

Concentration of phosphorus, potassium, and calcium in the leaves did not vary significantly among the treatments. The average percents were 0.17 for phosphorus, 0.94 for potassium, and 0.74 for calcium. All these concentrations are above those considered satisfactory for eastern blueberries (Trevett 1972). Nitrogen concentration in the leaves generally increased as the amount of fertilizer increased, but the 160-pound treatment did not differ significantly from the unfertilized control. Although the foliar nutrient concentration of plants in all treatments was similar, total nutrient uptake of plants in the higher treatments was greater because of their increased growth. This indicates that phosphorus, potassium, and calcium are present at high enough concentrations in the soil of the field area to provide for the increased growth from nitrogen fertilization without developing a deficiency in these elements. However, shortages of other nutrients may develop after the fields have been managed intensively. A close observation of the nutrient status of the bushes should therefore be maintained in order to monitor nutrient levels for potential shortages. If shortages do develop, fertilization for these other elements may be necessary. In addition, it would be worthwhile to analyze the various soil types on which the thin-leaved huckleberry grows, since soil type might affect the rate of fertilization and the elements contained in the fertilizer.

Although no data on berry production were gathered, it seems logical that berry production would be enhanced by fertilization, as is the case with eastern species. It would be valuable to verify this in the field. In addition, it might prove valuable to find out if the time of fertilizer application has an effect on the type of response, as is the case with eastern species of *Vaccinium*.

GREENHOUSE EXPERIMENTS

Methods

The greenhouse in which the studies were conducted was maintained at a 22° C day temperature and a 20° C night temperature, with no artificial illumination. Sand was used as the soil medium for the greenhouse nutrient studies. Methods outlined by Hewitt (1952) for sand preparation were generally followed. The sand was washed in a 3-percent solution of hydrochloric acid and then leached with distilled water to remove all traces of the acid. The size distribution of this sand was 12.6 percent larger than 1 mm, 52.4 percent between 0.5 and 1 mm, 27.2 percent between 0.25 and 0.5 mm, and 7.8 percent less than 0.25 mm.

The basic nutrient solution, from which all solutions used in the sand culture studies were derived, was first used by Arnon and Hoagland (1940) and is commonly known as Hoagland's solution. At full strength, it contains 18 meq/l of nitrogen, 6 meq/l of phosphorus, and 10 meq/l of potassium, as well as other necessary nutrients.

The first sand culture study was designed to determine the effect of nutrient solution pH on growth. The pH of a 1/10-strength Hoagland's solution was adjusted by adding either sulfuric acid or sodium hydroxide. Four pH treatments were replicated 10 times, using individually potted huckleberry seedlings. Treatments consisted of watering with nutrient solutions of pH 3.0, 4.0, 5.0, and 6.0. Each seedling was watered with nutrient solution three times a week and flushed with distilled water once a week, so that toxic concentrations of the nutrients could not build up in the sand. Stem length of each seedling was measured and recorded at the beginning of the study and at 2-week intervals thereafter. Ovendry weights of the seedlings were recorded at the end of the study in September 1973. Leaves of the seedlings were analyzed for nutrient concentration.

The second sand culture study was designed to determine the effect of various amounts and combinations of nitrogen, phosphorus, and potassium. Each nutrient solution treatment contained all three nutrients. The maximum (high) concentration of each was the concentration of that nutrient in full-strength Hoagland's solution. In addition, two other concentrations of 1/10-(medium) and 1/100-(low) strength Hoagland's solution were used. Concentrations of all nutrients other than nitrogen, phosphorus, and potassium were at the levels present in full-strength Hoagland's solution. By using the three nutrients together with three concentrations of each of the three named nutrients, 27 nutrient solutions were derived. All solutions were adjusted to pH 5.0 by adding sulfuric acid or sodium hydroxide. A total of 270 seedlings (10 replications of 27 treatments) was treated. Each seedling was watered with nutrient solution three times a week and flushed with distilled water once a week. The treatments were rotated around the greenhouse at 2-week intervals during the course of the study to minimize the effect of possible location differences. At the end of the study in September 1973, ovendry weight of each seedling was recorded and foliar analysis was performed on the leaves of the seedlings.

A third greenhouse study was designed to supplement the field fertilization study by demonstrating the fertilizer effect on huckleberry seedlings in a constant, favorable environment. One seedling was planted in each of 40 pots which were filled with soil from the field study area. Four treatments, each with 10 replications, were applied to these 40 pots. Fertilizer treatments of 0 (control), 10, 40, and 160 pounds of nitrogen per acre, in the form of ammonium sulfate, were applied in solution at the beginning of this study. The field soil was kept damp by watering with tapwater twice a week, but no other nutrients were added. Seedling shoot lengths were measured at the start of the study and at 2-week intervals. At the end of the study in

August 1973, after drying at 70° C for 5 days, seedling weights were determined and foliar analysis was performed on the leaves of the seedlings.

Results and Discussion

The huckleberry seedlings tolerated a wide range of pH values in the nutrient solutions, but leaf necrosis occurred in the pH 3.0 treatment, and there was less growth there than in the other three treatments (table 2). The pH 5.0 treatment had the best growth of all treatments but was not significantly better than the pH 4.0 or pH 6.0 treatments. Seedlings grown with pH 4.0, 5.0, and 6.0 treatments had relatively equal shoot growth throughout the study (fig. 1), and their root development was similar (fig. 2). Nutrient concentrations in the leaves of the seedlings of these three higher pH treatments were also similar. The nitrogen concentration of foliage from seedlings grown at pH 3.0 was slightly lower than the other three, but the potassium concentration of the pH 3.0 seedlings was over one-third higher.

Results of the nutrient study are summarized in tables 3-5. The levels of phosphorus and potassium, when analyzed individually, caused no significant seedling weight difference (table 3). However, the nitrogen levels produced highly significant differences, with the highest level of nitrogen yielding the greatest weight.

No significant interaction between phosphorus and potassium was found (table 4). The interaction of phosphorus and nitrogen was affected almost entirely by the level of nitrogen, with one exception--at the high level of nitrogen, the low level of phosphorus yielded significantly less growth than the medium or high level.

The interaction between nitrogen and potassium appears to be the most important, for significant interactions with potassium were present at all levels of nitrogen. At the high nitrogen level, the high potassium level produced significantly more growth than the medium or low levels of potassium. However, at the medium and low levels of nitrogen, the high level of potassium produced

Table 2.--*Average shoot length, ovendry weight, and foliage nutrient concentration of huckleberry seedlings after pH treatments*[1/]

Treatment (pH)	Length[2/]	Weight[2/]	N[3/]	P[3/]	K[3/]	Ca[3/]
	cm	*g*	- - - - - - - *Percent* - - - - - - -			
3.0	23.8*a*	0.63*a*	1.60	0.218	2.06	1.29
4.0	32.7*ab*	.84*ab*	1.75	.194	1.32	1.24
5.0	36.7*b*	1.19*b*	1.89	.219	1.54	1.19
6.0	34.3*ab*	.95*ab*	1.91	.206	1.47	1.19

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test.

[2/] Average of 10 observations.

[3/] Single determinations.

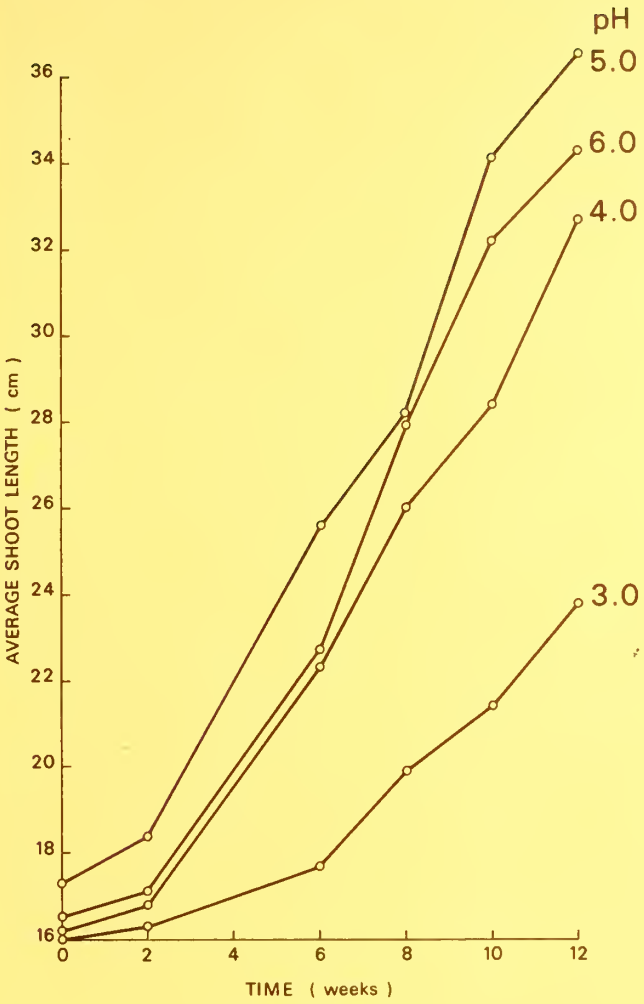

Figure 1.--Average shoot length growth of huckleberry seedlings grown at four pH levels.

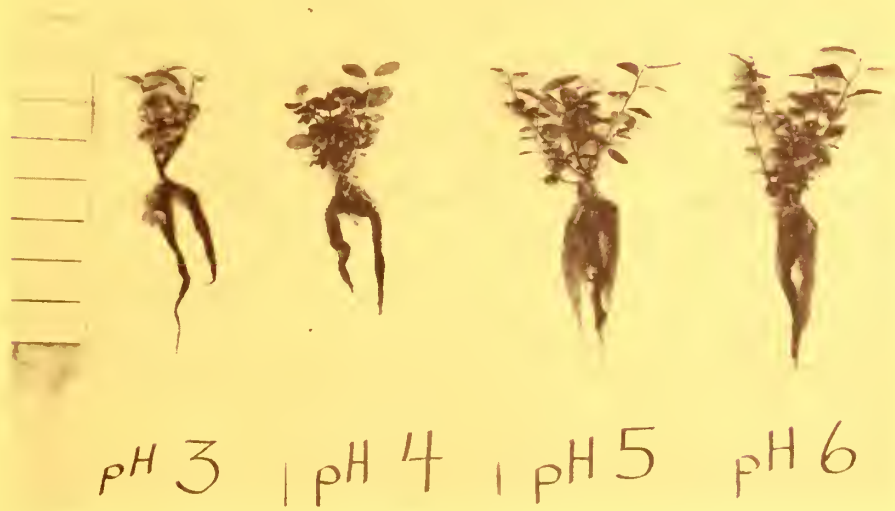

Figure 2.--Typical huckleberry seedlings at the end of the pH study. (Scale in inches)

Table 3.--*Individual element effects on average ovendry weight of huckleberry seedlings in nutrient study*[1/]

Nutrient level	N	P	K
	- - - - - - - - - - *g* - - - - - - - - - -		
High	1.02*a*	0.66*a*	0.63*a*
Medium	.51*b*	.66*a*	.61*a*
Low	.35*c*	.55*a*	.64*a*

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test. Each observation is the average of 90 seedlings.

Table 4.--*Two element interactions on average ovendry weight (grams) of huckleberry seedlings in nutrient study*[1/]

	High N	Medium N	Low N
High P	1.17*a*	0.47*b*	0.35*c*
Medium P	1.10*a*	.52*b*	.36*c*
Low P	.78*d*	.53*b*	.35*c*
	High N	Medium N	Low N
High K	1.31*a*	0.32*b*	0.26*c*
Medium K	.86*d*	.58*e*	.38*f*
Low K	.87*d*	.62*e*	.41*f*
	High P	Medium P	Low P
High K	0.63*a*	0.73*a*	0.56*a*
Medium K	.67*a*	.60*a*	.55*a*
Low K	.68*a*	.65*a*	.58*a*

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test. Each observation is the average of 30 seedlings.

Table 5.--*Percentage by dry weight of elements in seedling foliage after nutrient treatments*[1/]

Nutrient level	N	P	K
	- - - - - - - - *Percent* - - - - - - - -		
High	2.10*a*	0.206*a*	2.54*a*
Medium	1.21*a*	.156*b*	1.07*b*
Low	.76*c*	.144*b*	1.04*b*

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test. Each observation is the average of 9 treatments.

significantly less growth than the medium or low levels. The cause of this adverse effect is not apparent, but a possible explanation is that the huckleberry plants take up all the potassium that is available to them. Concentration of potassium in the plants may then reach a level that causes a nutrient imbalance if adequate nitrogen is not available. Therefore, additions of potassium by fertilization should be avoided unless potassium has been found to be the limiting factor in an individual field.

Each nitrogen level produced a significantly different foliar nitrogen concentration (table 5), with the high level having the highest concentration. The high levels of phosphorus and potassium in the solutions also produced significantly higher concentrations of these elements in the seedling leaves. However, the medium and low phosphorus and potassium levels did not produce significantly different concentrations in the leaves. No interaction between elements was found in relation to foliar nutrient concentration.

Results of the greenhouse study of field soil fertilization are summarized in table 6. The unfertilized control and 10 pounds of nitrogen per acre were not significantly different. However, the higher fertilization treatments produced significantly higher dry weight than the two low-level treatments. The increase in shoot length for the 40-pound and 160-pound treatments was more rapid and longer lasting than for the lower levels (fig. 3). Root development of the seedlings also was better at the two highest levels of fertilization (fig. 4). The highest nitrogen level produced the greatest growth. Seedlings fertilized at this level were significantly heavier than those given 40 pounds of nitrogen per acre.

None of the seedlings potted in soil from the field were harvested until the seedlings in the 160-pound treatment had stopped growing. Greenhouse

Table 6.--*Average shoot length, ovendry weight, and foliage nutrient concentration of huckleberry seedlings grown on fertilized field soil in the greenhouse*[1/]

Treatment (lb N/acre)	Length[2/]	Weight[2/]	N[3/]	P[3/]	K[3/]	Ca[3/]
	cm	*g*	- - - - - - - *Percent* - - - - - - -			
0	12.2*a*	0.54*a*	0.71	0.102	0.41	0.94
10	13.7*ab*	.62*a*	1.03	.120	.58	1.19
40	17.8*bc*	1.06*b*	1.16	.121	.64	1.26
160	23.0*c*	1.54*c*	1.43	.128	.83	1.29

[1/] Comparable means followed by the same letter are not significantly different (0.05 level) according to Duncan's multiple range test.

[2/] Each observation is the average of 10 seedlings.

[3/] Single determinations.

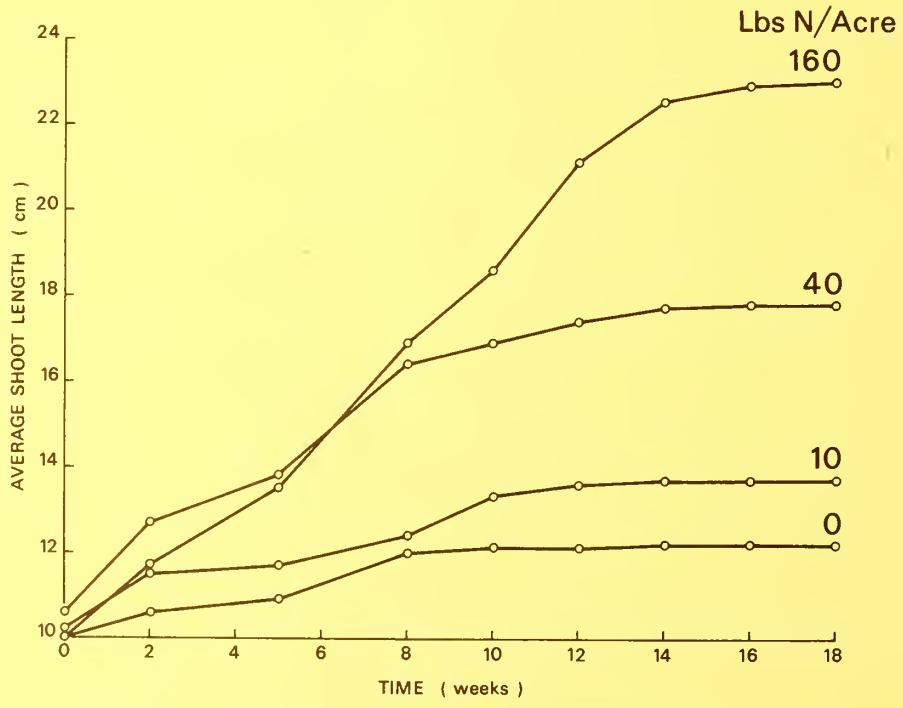

Figure 3.--Average shoot length growth of huckleberry seedlings grown on fertilized field soil in the greenhouse.

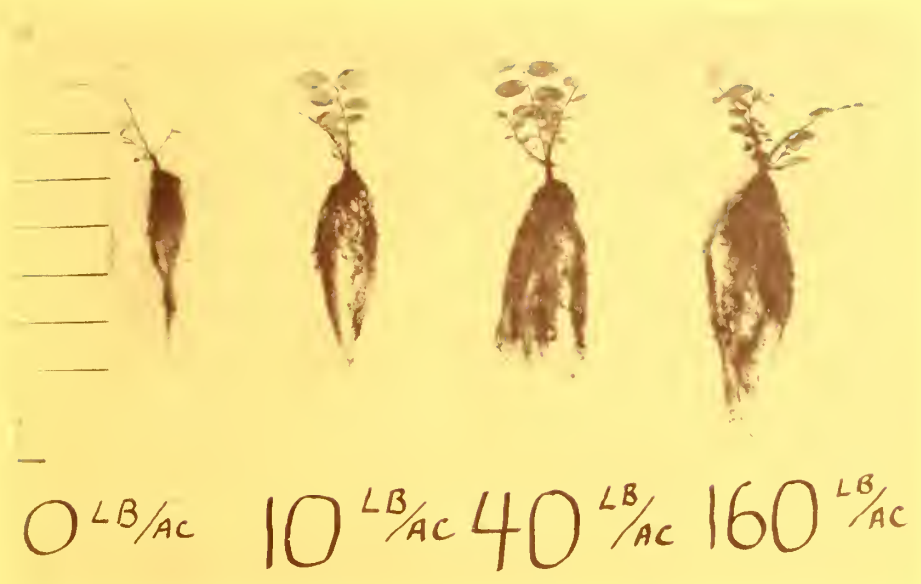

Figure 4.--Typical huckleberry seedlings after greenhouse growth on field soil fertilized with nitrogen. (Scale in inches)

conditions may have permitted a dilution of the nutrients in the leaves of the seedlings, and the foliar concentrations of nitrogen, phosphorus, and potassium were all lower than those found in the field.

All these studies indicate that growth of the thin-leaved huckleberry is increased by ammonium nitrogen fertilizer. The ammonium could be supplied by ammonium sulfate, as it was in this study, or by urea or other ammonium-containing fertilizers. It should be applied at a rate of 40 to 160 pounds of nitrogen per acre for maximum increase in growth.

LITERATURE CITED

Arnon, D. I., and D. R. Hoagland
1940. Crop production in artificial culture solutions and in soils with special reference to factors influencing yields and absorption of inorganic nutrients. Soil Sci. 50: 463-483.

Association of Official Agricultural Chemists
1950. Official methods of analysis. 7th ed., 910 p. Washington, D.C.

Bailey, John S., Bertram Gersten, Edward Vlach, and George W. Olanyk
1966. Response of Rubel blueberry bushes to ammonium sulfate and sulfate of potash-magnesia. Am. Soc. Hort. Sci. Proc. 89: 237-242.

_____, C. Tyson Smith, and Robert T. Weatherby
1949. The nutritional status of the cultivated blueberry as revealed by leaf analysis. Am. Soc. Hort. Sci. Proc. 54: 205-208.

Bailey, John S., A. F. Spelman, and Bertram Gersten
1962. Seasonal changes in the nutrients in the leaves of Rubel blueberry bushes. Am. Soc. Hort. Sci. Proc. 80: 327-330.

Ballinger, W. E., and E. F. Goldston
1967. Nutritional survey of Wolcott and Murphy blueberries (*Vaccinium corymbosum* L.) in eastern North Carolina. N.C. Agric. Exp. Stn. Tech. Bull. No. 178.

Boller, C. A.
1951. Growing blueberries in Oregon. Oreg. Agric. Exp. Stn. Bull. 499, 20 p.

Cain, John C.
1952. Comparison of ammonium and nitrate nitrogen for blueberries. Am. Soc. Hort. Sci. Proc. 59: 161-166.

Chapman, Homer D., and Parker F. Pratt
1961. Methods of analysis for soils, plants, and waters. Univ. Calif. Div. Agric. Sci.

Doehlert, Charles A., and John W. Shive
1936. Nutrition of blueberry (*Vaccinium corymbosum* L.) in sand cultures. Soil Sci. 41(1): 341-350.

Fiske, C. H., and Y. Subbarrow
1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66: 375-400.

Herath, H. M. E., and G. W. Eaton
1968. Some effects of water table, pH, and nitrogen fertilization upon growth and nutrient-element content of highbush blueberry plants. Am. Soc. Hort. Sci. Proc. 92: 274-283.

Hewitt, E. J.
1952. Sand and water culture methods used in the study of plant nutrition. Commonw. Bur. Hort. & Plantation Crops Tech. Commun. No. 22, 241 p.

Minore, Don
1972. The wild huckleberries of Oregon and Washington--a dwindling resource. USDA For. Serv. Res. Pap. PNW-143, 20 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Smith, W. W., Russel Eggert, A. R. Hodgdon, and A. F. Yeager
1946. Response of lowbush blueberries to fertilizers. Am. Soc. Hort. Sci. Proc. 48: 263-268.

Townsend, L. R.
1967. Effect of ammonium nitrogen and nitrate nitrogen, separately and in combination, on the growth of the highbush blueberry. Can. J. Plant Sci. 47(5): 555-562.

_____ and I. V. Hall
1970. Trends in nutrient levels of lowbush blueberry leaves during four consecutive years of sampling. Nat. Can. 97(4): 461-466.

Trevett, M. F.
1965a. Fertilizing lowbush blueberries is tricky. Maine Farm Res. 12(4): 35-42.

_____ 1965b. Spring or fall fertilization for lowbush blueberries. Maine Farm Res. 13(3): 11.

_____ 1972. A second approximation of leaf analysis standards for lowbush blueberry. Res. Life Sci. 19(15): 15-16.

_____ M. T. Hilborn, and L. W. Boulanger
1966. Keep lowbush blueberry leaves green. Maine Farm Res. 14(1): 12-14.

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USDA FOREST SERVICE RESEARCH NOTE

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SEVENTY-FIVE-YEAR-OLD DOUGLAS-FIR ON HIGH-QUALITY SITE RESPOND TO NITROGEN FERTILIZER

by

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ABSTRACT

Individually treated, 75-year-old, codominant, Douglas-fir trees growing on a highly productive site II soil responded well to nitrogenous fertilizers. Although the six treatments tested increased average 5-year basal area growth by 17 to 53 percent over control growth, only ammonium nitrate at 300-N dosage increased growth significantly. The six fertilizer treatments did not differ significantly among themselves; response to 300 pounds of nitrogen per acre (336 kg/ha) as urea was as good as that to 600-N (672 kg/ha) or to other elements in combination with 300-N.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, fertilizer response (forest tree), nitrogen fertilizer response, basal area increment, silviculture.

INTRODUCTION

Fertilization is a practical silvicultural tool. However, to maximize its usefulness, we must know where response can be expected from specific treatments and to what extent growth will be increased. The results obtained after fertilizing codominant trees in a highly productive, 75-year-old stand add important information to our knowledge.

Our study was designed to provide answers to five questions, as they pertain to this site and stand condition: (1) Is growth increased by addition of nitrogen? (2) How does response vary by amount of nitrogen added? (3) Does source of nitrogen make any difference? (4) Does addition of other elements, with nitrogen, affect the response? (5) What is the duration of response? We report 5-year basal area growth of individually treated codominant trees.

STUDY AREA

The study area is on the McCleary Experimental Forest,[1/] near McCleary, Washington. It lies on gently sloping ground at an elevation of about 400 feet (122 m). Both climate and soil favor rapid tree growth. A nearby weather station, at Elma , shows an average annual precipitation of 66 inches (168 cm), with 14 inches (36 cm) from April through September. Average annual temperature is 51° F (11° C); average temperature from April through September is 58° F (14° C). The average frost-free growing season is about 185 days. The soils, which are derived from glacial till with some admixture from underlying basalt, are Tebo gravelly loams--both normal and wet phases.[2/] Site index averages about 180--site II.

The stand originated after repeated fires and is nearly pure Douglas-fir (fig. 1). It was 74 years old when the fertilizer study was begun in spring 1968. Prior to that, the stand had been thinned four times at 5-year intervals, the most recent being in the summer of 1965. At age 74, there were about 70 trees per acre (173/ha), with an average d.b.h. of 23 inches (58 cm) and a volume of 10,000 cubic feet (753 m^3/ha).

[1/] Maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with Simpson Timber Company.

[2/] Carl McMurphy, Soil Conservation Service, Olympia, Washington, personal communication. Soil had previously been classified as Olympic loam.

Figure 1.--Typical stand conditions prior to fertilization in the repeatedly thinned portion of the McCleary Experimental Forest.

METHODS

FERTILIZER TREATMENTS

We tested seven treatments, including a control (table 1). Based on field tests at other locations, we selected most promising elements, combinations, and application rates. Nitrogen, alone or combined with other elements, was applied to all fertilized trees; this choice was based on considerable existing evidence that insufficient available nitrogen generally limits Douglas-fir growth in the Pacific Northwest.

Each treatment was randomly assigned to 6 trees of the 42 selected codominant Douglas-firs, scattered over a 25-acre (10-ha) area. No study tree was closer

Table 1.--*Treatments and corresponding amounts of elements and fertilizers applied*

Treatment number	Element				Fertilizer	
	N	P	K	S	Name	Amount
	Pounds per acre[1/]					*Pounds per acre*[1/]
1	0	0	0	0	--	--
2	300	0	0	0	Ammonium nitrate (33.5 percent N)	895.5
3	300	0	0	0	Urea (46 percent N)	652.2
4	600	0	0	0	Urea	1,304.3
5[2/]	300	150	0	0	Urea	652.2
					Treble superphosphate (19.6 percent P, 1 percent S, and 12 percent Ca)	765.3
6[2/]	300	150	0	50	Urea	652.2
					Treble superphosphate	765.3
					Soil sulfur (99 percent S)	50.5
7[2/]	300	150	100	50	Urea	652.2
					Treble superphosphate	765.3
					Soil sulfur	50.5
					Potassium chloride (60 percent K and 0.3 percent Ca)	20.1

[1/] Pounds per acre x 1.12 = kg/ha.

[2/] Trees fertilized with treble superphosphate received additional, but small, amounts of S and Ca (7.6 and 9.2 pounds per acre, respectively).

than 90 feet (27 m) to another. All were undamaged and apparently healthy.[3] Fertilizer was evenly distributed over a 0.1-acre (0.04-ha) area surrounding each designated tree; thus, both the subject trees and their nearest neighbors were treated.

Application was made on April 9 and 10, 1968, during sunny weather on moist soil. During the 7 days after fertilization, skies were overcast and about 1.6 inches (4.1 cm) of rain were measured at nearby Elma. Thus, weather conditions were unlikely to have led to gaseous losses of N as have been reported for urea applications during dry, hot weather.[4]

MEASUREMENTS AND ANALYSES

To measure growth and response, two to six cores were extracted from each tree 5 years after treatment. These, along with d.b.h. and bark thickness measurements taken at the same time, provided the basis for measuring pretreatment growth and subsequent response.[5] The core-length from cambium to each annual ring, through that formed 8 years before treatment, was measured and recorded to the nearest 0.02 inch (0.05 cm). These measurements were then converted to overbark basal area in each year and to annual basal area growth. From this we computed periodic basal area growth for (1) the two 4-year periods prior to fertilization and (2) the 5-year periods both after and before treatment.

The effect of treatment on 5-year basal area growth was determined by analyses of covariance. Differences in mean posttreatment growth were tested for statistical significance at the 5-percent probability level using Scheffe's test.[6]

RESULTS

FIVE-YEAR PERIODIC GROWTH

We believed that response of trees to treatment might be affected by their competitive status, especially since some of them had been released, to varying degrees, by the thinning two to three growing seasons before fertilization. Our cores showed that radial growth was declining on some and improving on others. Therefore, we decided to use this change in growth rate as an index of pretreatment competitive status and calculated the ratio of growth during the most recent 4 years to that during the previous 4 years. Although ratios varied from 0.82 to 1.68, posttreatment growth of trees was not significantly correlated with our index of competitive status.

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[3] Subsequently, three of the study trees, each treated differently, were accidentally cut. Thus, three of the seven treatments were left with only five trees.

[4] S. H. Watkins, R. F. Strand, D. S. DeBell, and J. Esch, Jr. Factors influencing ammonia losses from urea applied to northwestern forest soils. Soil Science Society of America Proceedings 36: 354-357, illus., 1972.

[5] We initially took two cores per tree, from opposite ends of an average diameter. Annual d.b.h. measurements with a diameter tape were used to judge reliability of these cores for determining past growth. If the two sets of measurements did not reasonably agree, additional cores were taken to improve accuracy.

[6] George W. Snedecor and William G. Cochran. Statistical methods. Ames, Iowa State University Press, ed. 6, 593 p., illus., 1967.

Posttreatment growth was significantly correlated with pretreatment basal area and, more strongly, with pretreatment growth rate (fig. 2). Therefore, to separate effects of treatment from effects of different pretreatment growth rates, data were adjusted by covariance analysis to a common pretreatment growth rate (0.0396 square foot (0.00368 m^2) per tree per year).

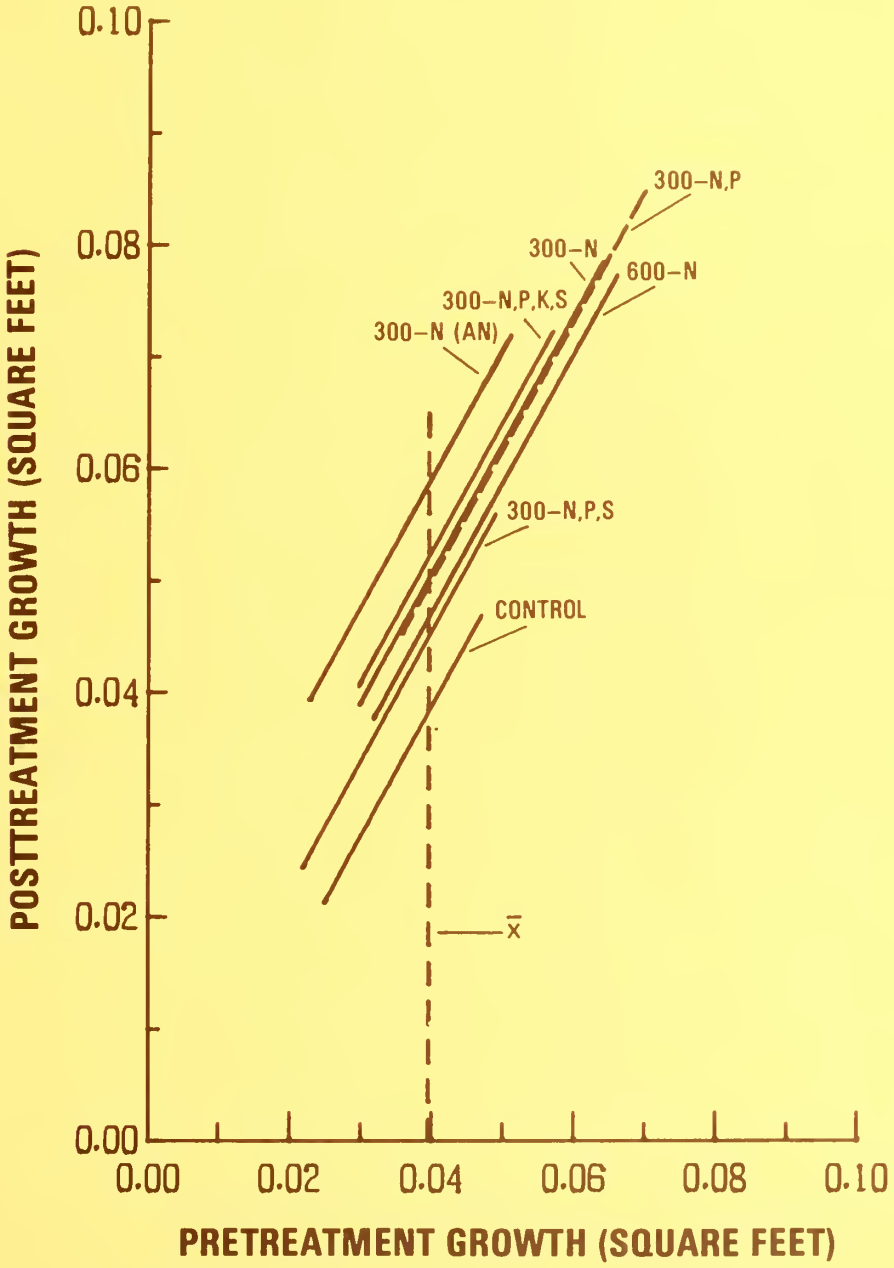

Figure 2.--Periodic annual basal area growth during 5-year periods before and after treatment.

There evidently was a response to added nitrogen; growth with all six fertilizer treatments averaged greater than growth without fertilizer (table 2). Adjusted means for fertilizer treatments were 17 to 53 percent greater than that without fertilizer; however, differences among fertilizer treatments were nonsignificant. The only significant increase was for ammonium nitrate--53 percent over the control. Although ammonium nitrate appeared superior to urea as a source of nitrogen, this difference was not statistically significant. Response to 600 pounds (672 kg/ha) of nitrogen was no better than response to 300 pounds (336 kg/ha); thus, the optimum level of nitrogen might have been more or less than 300 pounds. Likewise, no additional growth was gained by supplying other elements along with nitrogen.

Table 2.--*Effect of treatment on periodic annual basal area growth per tree (treatment averages)*

Treatment	5-year p.a.i.		Ratio[1/]	Adjusted p.a.i.	Increase
	Before	After			
	- -*Square feet*[2/] - -			*Square feet*[2/]	*Percent*
Control	0.0364	0.0346	0.95	0.0384	0
300-N, P, S	.0374	.0424	1.13	.0450	17
600-N	.0426	.0502	1.18	.0468	22
300-N, P	.0473	.0585	1.24	.0496	29
300-N	.0430	.0542	1.26	.0503	31
300-N,P,K,S	.0378	.0500	1.32	.0522	36
300-N (AN)	.0323	.0503	1.56	.0589	53

NOTE: Values connected by the same line do not differ significantly at 5-percent probability level.

[1/] After:before.

[2/] Square feet x 0.0929 = square meters.

TRENDS IN GROWTH OVER TIME

Trends over time show when response began and peaked; they suggest how long response may last. Trends also indicate possible relationships between response and differences in pretreatment growth patterns. The trends shown are generally supported by the individual-tree growth upon which these averages are based; the greatest variation around these trends was with the NPS treatment. Differences in trends were not statistically tested.

There was an immediate response in 1968 to all fertilizer treatments; in each year thereafter, growth was better for all fertilizer treatments than for the control (fig. 3). However, differences in pretreatment growth patterns cast

Figure 3.--Trends in adjusted growth over time, relative to control growth.

doubt upon the exact effect of treatment. By chance, trees fertilized with ammonium nitrate not only tended to have the lowest average pretreatment growth rate, but also had a steadily improving growth rate prior to fertilizer treatment. This was presumably a response to the 1965 thinning and could be responsible, in part, for ammonium nitrate giving the greatest apparent increase in growth.

Response to most treatments peaked in the second year following treatment. Otherwise, trends are quite erratic and cannot be readily explained. Fertilizer effects will probably continue after this 5-year observation period; however, there is no clear indication that the effectiveness of one treatment will last longer than that of another.

DISCUSSION AND CONCLUSIONS

Our index of competitive status was not a significant variable. This lack of statistical significance does not necessarily mean that such factors as recency and amount of release received in thinnings do not affect the tree's response to fertilizer; for example, the growth trend with the ammonium nitrate treatment strongly suggests an interaction of the thinning and fertilizing treatments. Thus, caution should be exercised when interpreting the apparent differences in effectiveness of fertilizer treatments, especially in thinned stands.

Our study results suggest the following conclusions:

1. Nitrogenous fertilizers increased basal area growth of these codominant Douglas-fir.

2. Ammonium nitrate appears superior to urea as a source of nitrogen, but this superiority may, in part, be due to pretreatment growth trends. Our conclusion is provisional.

3. Response to 300 pounds of nitrogen per acre (336 kg/ha) as urea was at least as good as that to 600-N or to other elements in combination with 300-N.

4. Response to all fertilizer treatments will continue for longer than this 5-year observation period; a future reevaluation is necessary.

On this highly productive site, fertilizing increased basal area growth of mature trees by an average of about 30 percent. Increases in cross-sectional area growth at higher levels on the stem and in volume growth may be a little less.[7/]

We must now relate these responses to expectations with operational fertilization. Would broadcast application of fertilizer increase basal area growth per acre as much as it increased growth of these trees? We are testing this in a followup trial by comparing the effect of ammonium nitrate and urea on this same experimental forest. We anticipate that total stand response will be similar in magnitude to that of individually treated codominant trees.

Increased growth by fertilizing mature stands such as this has an obvious economic significance; a large proportion of this growth is merchantable and has a high unit value. Moreover, this growth can soon be removed in harvest.

7/ H. Brix and L. F. Ebell. Effects of nitrogen fertilization on growth, leaf area, and photosynthesis rate in Douglas-fir. Forest Science 15(2): 189-196, illus., 1969.

GPO 991-896

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

3.79:PNW-238

PNW-238

November 1974

REPEATED SPRAYING TO CONTROL FOUR COASTAL BRUSH SPECIES

by

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FEB 21 1975
SCI., TECH. & AGR. DIV.

ABSTRACT

Resprouting salmonberry, western thimbleberry, vine maple, and California hazel shrubs were readily controlled by a respray of 2,4,5-T applied as an early foliar treatment. A respray of amitrole-T or picloram did not appreciably increase degree of control compared with the initial application.

KEYWORDS: Herbicides, (- brush control, silvicultural control, salmonberry, thimbleberry, vine maple, California hazel.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Research and field experience during the past 20 years have proven herbicidal sprays to be an effective method for controlling competing shrubs and weed trees on forest lands in the Oregon and Washington Coast Ranges. However, silvicultural use of herbicides is complicated and requires careful selection of chemical, dosage, and carrier. Proper selection of treatments for the variety of brush conditions found on coastal sites requires knowledge of individual species' response to herbicides to accurately predict the results of selected treatments.

Information is available for single applications of herbicides on major species that compete with conifers (Krygier and Ruth 1961, Stewart 1974a, 1974b), but many species resprout and are not adequately controlled by one application. Repeated applications are often required to achieve the desired degree of control. To assess desirability of respraying, foresters must know the effects of successive applications of herbicides on these species. At present, this information is available only for southwest Oregon brush species (Gratkowski 1968). The tests reported here provide the same information for four major shrub species found on forest lands in the Coast Ranges.

MATERIALS AND METHODS

During 1970, selected formulations of herbicides were tested as early foliar and midsummer sprays on six of the most common brush species on forest lands in the Oregon Coast Ranges (Stewart 1974b). Each herbicidal treatment was applied as a foliage spray to drip point using knapsack sprayers. Sprays were applied on 10 individual shrubs of each species in a completely randomized design. Red alder (*Alnus rubra*) trees less than 12 feet (3.6 meters) high proved highly susceptible to herbicides and were readily killed with one application; salal (*Gaultheria shallon*) was resistant to all herbicides tested. The remaining four species, salmonberry (*Rubus spectabilis*), western thimbleberry (*Rubus parviflorus*), vine maple (*Acer circinatum*), and California hazel (*Corylus cornuta* var. *californica*) were intermediate in response. Surviving shrubs of these species sprouted from stems and roots the following year.

In May 1972, resprouting shrubs in the original plots were again sprayed with the same formulations of herbicides. Only the most effective treatments from the 1970 tests were included in the respray treatments. These tests were designed to determine the cumulative degree of control resulting from repeated early foliar applications of herbicides.

Herbicides[1/] used were:

Herbicide	Formulation
2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid]	Propylene glycol butyl ether ester
Silvex [2-(2,4,5-trichlorophenoxy) propionic acid]	Propylene glycol butyl ether ester
Amitrole-T [a 1:1 mixture of 3-amino-*s*-triazole and ammonium thiocyanate]	Water-soluble liquid
Picloram [4-amino-3,5,6-trichloropicolinic acid]	Potassium salt

The herbicide 2,4,5-T was applied in a 3-percent diesel oil-in-water emulsion on salmonberry and western thimbleberry shrubs and in water on vine maple and California hazel. All other herbicides were applied in water carriers.

[1/] Test samples of 2,4,5-T, silvex, and picloram were provided by The Dow Chemical Company; Amchem Products, Inc. provided the amitrole-T. This cooperation is appreciated.

Shrubs resprouting after the original early foliar and midsummer applications were resprayed during the early foliar season when three-fourths of the leaves of all four brush species were fully developed and plants were actively growing. This period is generally regarded as optimum for applying herbicides as foliage sprays. Treatment effects were evaluated during September of 1973, 16 months after the resprays were applied. This examination indicated that all four species could be adequately controlled for site preparation or release of small conifers by two applications of the most effective herbicides. Therefore, additional resprays on the remaining live shrubs were not necessary, and the study was terminated.

RESULTS AND DISCUSSION

Cumulative plant kill resulting from early foliar or midsummer sprays on mature shrubs and early foliar resprays on resprouting shrubs is shown in table 1. Resprays of 2,4,5-T were very effective on most species, especially at the lower rates of application. In many cases, the second application at least doubled the number of plants killed. This agrees with previous results for southwest Oregon species that indicate resprouting shrubs are easier to kill than full-crowned mature plants (Gratkowski 1968).

Table 1.--*Cumulative percentage of shrubs killed by repeated sprays on mature (1970) and resprouting (1972) brush species*

Species and herbicide	Concentration	Carrier	Early[1/] foliar spray, 1970	Early[1/] foliar respray, 1972	Midsummer spray, 1970	Early[1/] foliar respray, 1972
	lb aehg		--------*Percentage of shrubs killed*----------			
Salmonberry:						
2,4,5-T	3	Emulsion	50	90	40	100
Amitrole-T	1	Water	70	70	70	70
	3	Water	80	80	70	80
Picloram	1	Water	70	90	100	--
Western thimbleberry:						
2,4,5-T	3	Emulsion	50	90	60	90
Amitrole-T	1	Water	10	20	0	0
	3	Water	20	50	0	30
Picloram	1	Water	70	100	80	90
Vine maple:						
2,4,5-T	1	Water	0	20	0	20
	3	Water	40	80	30	80
Silvex	1	Water	10	30	0	50
	3	Water	30	50	30	60
Picloram	1	Water	40	80	30	80
California hazel:						
2,4,5-T	1	Water	20	80	10	50
	3	Water	60	100	40	80
Silvex	1	Water	40	70	0	10
	3	Water	10	70	20	60
Picloram	1	Water	80	100	70	100

1/ When 3/4 of the leaves were fully developed.

Resprays of picloram, highly effective on mature plants, were justified only on vine maple. However, a respray of the less expensive herbicide 2,4,5-T produced results equivalent to that obtained with picloram.

A respray of amitrole-T had little effect on western thimbleberry and did not increase control of salmonberry. Such sprays would only tend to hasten conversion of salmonberry-western thimbleberry communities to western thimbleberry. In contrast, a respray of 2,4,5-T 1 or 2 years later would virtually eliminate both species. These results show that one foliage spray of 2,4,5-T may not adequately control well-established mature salmonberry shrubs. On the other hand, small seedlings or succulent resprouting shrubs should be very susceptible. Therefore, early recognition of a developing brush problem is critical if we are to reduce the need for resprays.

For conifer release, the objective is to increase the amount of light reaching young conifers and reduce shrub competition for soil moisture and nutrients (Gratkowski 1961). It is usually necessary only to obtain a high percentage of defoliation, a fair amount of topkill, and a minimum of resprouting. For brushfield reclamation, however, a high percentage of the shrubs must be killed and resprouting must be limited. Control adequate to release well-established conifers can be obtained with one spray of 2,4,5-T on red alder less than 12 feet (3.6 meters) high, salmonberry, western thimbleberry, vine maple, and California hazel (Stewart 1974b). For releasing small conifers or for reclamation, a second spray of 2,4,5-T should produce adequate control of salmonberry, western thimbleberry, vine maple, and California hazel. A single application of picloram, a nonselective herbicide, may be adequate for site preparation or reclamation on these species.

LITERATURE CITED

Gratkowski, H.
1961. Use of herbicides on forest lands in southwest Oregon. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn. Res. Note No. 217, 18 p., illus. Portland, Oreg.

———
1968. Repeated spraying to control southwest Oregon brush species. USDA For. Serv. Res. Pap. PNW-59, 6 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Krygier, James T., and Robert H. Ruth
1961. Effect of herbicides on salmonberry and on Sitka spruce and western hemlock seedlings. Weeds 9(3): 416-422, illus.

Stewart, R. E.
1974a. Budbreak sprays for site preparation and release from six coastal brush species. USDA For. Serv. Res. Pap. PNW-176, 20 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

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1974b. Foliage sprays for site preparation and release from six coastal brush species. USDA For. Serv. Res. Pap. PNW-172, 18 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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LASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

A 99.9:PNW-239

PNW-239 November 1974

VOLUME EQUATIONS FOR SECOND-GROWTH DOUGLAS-FIR

by

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and

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CLEMSON UNIVERSITY LIBRARY
APR 18 1975
SCI., TECH. & AGR. DIV.

ABSTRACT

This note presents volume equations and tables for second-growth Douglas-fir.

Keywords: Volume measurement (tree), Douglas-fir.

A request for a volume equation giving reasonable values for small Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) led to a study of methods of preparing such volume tables. Although results of this study will not be reported here, we mention it to assure prospective users that the volume equations have a sound theoretical basis and, in the sense of minimizing squared residual variation, are the best fitting that could be found for the 1,127 trees in the sample.[1/] The root mean square variations for both volume and form factor were the test criteria.

[1/] Cooperation of the following in providing stem analysis data is gratefully acknowledged: Weyerhaeuser Company, Canadian Forest Service, University of British Columbia, Oregon State University, Washington Department of Natural Resources, and the Intensive Culture of Douglas-fir Project of the Pacific Northwest Forest and Range Experiment Station.

The sample included trees from young stands in Oregon, Washington, and British Columbia. It included more low-elevation than high-elevation trees. Tree size ranged from 0.4 inch by 6 feet to 32 inches by 167 feet (table 1). Because of diverse sources of data, independent variables were limited to total height and diameter at breast height (b.h.) outside bark (o.b.) and inside bark (i.b.). The dependent variable was form factor, based on total cubic volume i.b. including a stump calculated as a cylinder. Stump heights were as cut, but data were collected recently so low stumps were the rule.

Two sets of equations were needed: one for very small trees and one for larger trees. There is no definite breaking point between these categories. The one chosen was 18 feet. At this height, the two equations give virtually identical volume estimates within the range of the data.

The two sets of equations follow:

H = total height in feet
D = d.o.b. at b.h. in inches
FO = outside bark form factor (FOS or FOL)
V = total volume including stump and tip in cubic feet (VS or VL)
if $H < 18$ feet calculate FOS (basis 59 trees)
if $H > 18$ feet calculate FOL (basis 1,068 trees)

$$FOS = 0.406098(H-0.9)^2/(H-4.5)^2 - 0.0762998\ D(H-0.9)^3/(H-4.5)^3 + 0.00262615\ DH(H-0.9)^3/(H-4.5)^3$$

$$VS = 0.005454154\ FOS(D^2H)$$

$$FOL = 0.480961 + 42.46542/H^2 - 10.99643\ D/H^2 - 0.107809\ D/H - 0.00409083\ D$$

$$VL = 0.005454154\ FOL(D^2H)$$

These equations had root mean square errors of 12.2 and 8.0 percent for FOS and FOL, respectively; 12.7 and 16.8 percent for VS and VL.

Volumes calculated from these equations appear in tables 2 and 3.

In table 2, the increases in volume with decreases in height for small trees of equal diameter result from diameter being measured 4.5 feet above ground.

For those who want to compare a logarithmic volume equation with these equations, the following had the lowest squared deviations when fit in the form stated: $\log(V-0.14) = -2.5869 + 1.0619 \log H + 1.8159 \log D$. This had a root mean square error of 12.1 percent for form factor and 18.9 percent for volume estimates.

Table 1.--Number of trees in sample

D.b.h. (inches)	Height (feet)																	Total
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	
<0.5	1																	1
1	34	8																42
2	10	49	6															65
3		16	54	5														75
4			32	11	2													45
5		1	14	25	10	3	1		1									55
6			1	32	15	14	15	6										83
7			2	13	18	10	19	15	3									80
8				2	21	3	22	26	3	2								79
9				3	12	8	8	34	15	5	1							86
10					1	6	9	23	17	10		2						68
11				1	1	2	10	11	22	12	3	2						64
12						1	3	9	18	22	5	2	1	1				62
13							3	7	6	21	14	6	1					58
14							1	4	9	16	9	7	1	2				49
15							1	1	10	6	4	4	3	2	1			32
16								1	2	6	8	7	6	3	1			34
17									1	2	4	4	3	2	1			17
18									1	2		5	5	2		1		16
19									1	5	3	1	5	3	2			20
20											2	2	2	3		3		12
21										2	2	3	6	3	6	1		23
22										1	2	5	2	2		3		15
23										2			1		2	2	3	10
24												2		1		4		7
25												1		2		1	1	5
26										1	1	1		1	3	1		8
27											2			3			1	6
28												1		1	1			3
29																1	1	2
30														3	1			4
31																		
32																	1	1
Total	45	74	109	92	80	47	92	137	109	115	60	55	36	34	18	17	7	1,127

Table 2.--Estimated cubic-foot volume, Douglas-fir under 18 feet in height, including stump and tip--basis 59 trees

D.b.h. (inches)	Height (feet)												
	6	7	8	9	10	11	12	13	14	15	16	17	18
.4	0.020	0.013											
.5	.029	.019	0.016	0.014	0.014								
.6	.038	.026	.022	.020	.019								
.7	.049	.034	.029	.026	.025	0.025	0.025	0.026					
.8	.058	.043	.036	.034	.032	.032	.032	.033	0.034	0.035			
.9	.068	.051	.044	.041	.040	.040	.040	.041	.042	.043	0.045	0.046	
1.0		.060	.053	.050	.048	.048	.049	.050	.051	.053	.054	.056	
1.1		.069	.061	.058	.057	.057	.058	.059	.061	.063	.065	.067	0.070
1.2			.070	.067	.066	.066	.067	.069	.071	.074	.076	.079	.082
1.3			.079	.076	.075	.076	.078	.080	.082	.085	.088	.092	.095
1.4				.085	.085	.086	.088	.091	.094	.097	.101	.105	.109
1.5				.094	.095	.096	.099	.102	.106	.110	.115	.119	.124
1.6					.105	.107	.110	.114	.119	.123	.129	.134	.140
1.7					.115	.118	.122	.126	.132	.137	.143	.150	.156
1.8					.124	.128	.133	.139	.145	.151	.158	.166	.173
1.9					.134	.139	.145	.151	.159	.166	.174	.182	.191
2.0						.150	.157	.164	.173	.181	.190	.200	.210
2.1						.161	.169	.177	.187	.196	.207	.217	.228
2.2							.181	.191	.201	.212	.224	.236	.248
2.3							.192	.204	.216	.228	.241	.254	.268
2.4								.217	.230	.244	.258	.273	.288
2.5								.230	.245	.260	.276	.292	.309
2.6									.259	.276	.294	.312	.331
2.7									.274	.293	.312	.332	.352
2.8										.309	.330	.352	.374
2.9										.326	.349	.372	.397
3.0											.367	.393	.419
3.1											.385	.413	.442
3.2											.404	.434	.465
3.3												.455	.488
3.4												.476	.512
3.5												.496	.535

Table 3.--Estimated cubic-foot volume, Douglas-fir, over 18 feet in height (including stump and tip)--basis 1,068 trees

D.b.h. (inches)	Height (feet)																
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	0.06																
2	.22	0.32															
3	.47	.69	0.92														
4	.77	1.17	1.58	1.99	2.39	2.80	3.20	3.61									
5	1.10	1.75	2.40	3.03	3.67	4.30	4.93	5.56	6.19								
6	1.43	2.41	3.34	4.26	5.17	6.08	6.98	7.89	8.79								
7	1.75	3.12	4.40	5.66	6.90	8.13	9.35	10.6	11.8								
8		3.86	5.56	7.20	8.82	10.4	12.0	13.6	15.2	16.8							
9		4.63	6.80	8.88	10.9	13.0	15.0	17.0	18.9	20.9	22.9						
10		5.39	8.09	10.7	13.2	15.7	18.2	20.6	23.0	25.5	27.9	30.3					
11			9.43	12.6	15.6	18.6	21.6	24.5	27.5	30.4	33.3	36.2	39.1				
12			10.8	14.5	18.2	21.7	25.2	28.7	32.2	35.7	39.1	42.5	46.0	49.4			
13				16.6	20.8	25.0	29.1	33.2	37.2	41.2	45.2	49.3	53.3	57.2			
14					23.6	28.4	33.1	37.8	42.5	47.1	51.7	56.4	61.0	65.5			
15					26.4	31.9	37.3	42.7	48.0	53.3	58.6	63.8	69.0	74.2	79.5		
16						35.5	41.7	47.7	53.7	59.7	65.7	71.6	77.5	83.4	89.3		
17						39.2	46.1	53.0	59.7	66.4	73.0	79.7	86.3	92.9	99.5		
18							50.7	58.3	65.8	73.3	80.7	88.0	95.4	103	110	117	
19							55.4	63.8	72.1	80.3	88.5	96.7	105	113	121	129	
20							60.1	69.4	78.5	87.6	96.6	106	114	123	132	141	150
21								75.0	85.0	95.0	105	115	124	134	144	153	163
22								80.8	91.7	102	113	124	134	145	156	166	177
23								86.6	98.4	110	122	133	145	156	168	179	190
24								92.4	105	118	130	143	155	168	180	192	204
25								98.2	112	126	139	153	166	179	192	206	219
26								104	119	133	148	162	177	191	205	219	233
27									126	141	157	172	187	203	218	233	248
28										149	166	182	198	215	231	247	263
29											175	192	209	226	244	261	278
30												202	220	238	257	275	293
31													231	250	270	289	308
32													242	262	283	303	323
33														274	296	317	338

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-240 February 1975

IMMOBILIZATION OF ROCKY MOUNTAIN ELK USING POWDERED SUCCINYLCHOLINE CHLORIDE [1/]

by

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ABSTRACT

After being captured in traps, 78 Rocky Mountain elk (Cervus canadensis nelsoni) *were successfully immobilized with dry powder charges of succinylcholine chloride during June and July 1971-73. The average dosage was 26.4 mg, with an average latency of 7.1 minutes and duration of 24.5 minutes. There were no significant (P>0.01) differences between sexes, age classes, or years for latent period or duration of immobilization. There was a significant difference between 1971-72 and 1973 for amount of drug required. Four drug-related deaths occurred.*

Keywords: Rocky Mountain elk, *Cervus canadensis nelsoni*, drug injection.

[1/] This paper is an outgrowth of a cooperative study between the Oregon Wildlife Commission (Pittman-Robertson Project W-70-R) and the U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

INTRODUCTION

The neuromuscular blocking action of succinylcholine chloride was reported by Castillo and DeBeer (1950). The use of succinylcholine chloride in aqueous solution to immobilize Rocky Mountain (*Cervus canadensis nelsoni*) and Roosevelt (*Cervus canadensis roosevelti* Merriam) elk has been reported by Flook et al. (1962) and Harper (1965). Preloaded darts containing powdered succinylcholine chloride eliminate refrigeration and the time-consuming job of mixing and loading fresh darts each day with various combinations of liquid drug and sterile water.

Our purpose is to report data on doses of powdered succinylcholine chloride suitable for immobilizing Rocky Mountain elk.

METHODS

Rocky Mountain elk from the Blue Mountains of northeast Oregon were captured in panel traps during June and July 1971-73. Traps were checked daily and captured elk immobilized before ear tags and transmitters were attached. Powdered succinylcholine chloride was administered by darts (Pneu-Dart Model No. P1) fired from a CO_2-powered rifle (Pneu-Dart Model No. 167).[2/] Mechanics of the Pneu-Dart have been described by Liscinsky et al. (1969). Darts used in this study contained from 10 to 30 mg of drug. Trapped elk were cautiously approached on foot, downwind, to minimize disturbance and shot in the hip or shoulder at a distance of 20 feet or less. Elk were usually immobilized with a single dart, but on occasion, two or more darts were necessary to obtain the desired dosage.

Each animal was ranked in one of three categories depending upon the degree of immobilization. Category I animals were incompletely immobilized, remained recumbent, and needed restraint. Elk in category II were immobilized, unable to move, and exhibited no distress. Those in category III were immobilized and exhibited distressed breathing, heart pounding, and no eye control.

RESULTS AND DISCUSSION

Powdered succinylcholine chloride can be successfully used to immobilize Rocky Mountain elk. During three trapping seasons, 78 elk were immobilized. Complete data were collected on 74 elk (table 1)--61 elk were successfully immobilized with a single dart and 17, with two or more darts.

In 1971, the initial dosage selected was 16 mg, following the recommendations of Harper (1965) and Flook et al. (1962), but this dosage proved unsatisfactory. Flook et al. noted that some elk tolerated much heavier dosage rates than others of the same sex-age class. Harper made no attempt to estimate weights because the dosage was not altered in relation to the size of the elk. We found dosage based on sex, age, and weight unsatisfactory because of the variablility between animals. More predictable results were obtained by shooting all elk with a minimum 20-mg dosage.

[2/] Mention of product by name does not imply endorsement by the U.S. Forest Service.

Table 1.--*Quantity of succinylcholine chloride used, latent time, and duration time related to immobilization*

Sex and age	Number	Drug	Range	Latency	Duration
		- - - Milligrams - - -		*- - - Minutes - - -*	
Males (12-14 months)	24	26.03(7.23)	12-40	7.6(2.77)	16.3(16.79)
Females (12-14 months)	24	22.33(10.58)	16-40	5.7(4.50)	25.6(9.86)
Females (2-10 years)	26	27.73(10.97)	20-40	7.3(3.24)	31.5(16.76)
All elk	74	26.44(10.26)	12-40	7.1(3.76)	24.5(15.82)

Note: Standard deviation in parentheses.

Ten elk failed to immobilize and were shot with a second dart following a time lapse of 30 minutes to 3 hours. A time delay of this range proved undesirable because two elk died, and eight were never immobilized. The best procedure was to meet or slightly exceed the required dosage with the initial shot as opposed to using two or more darts, separated by a time lag, to achieve immobilization. However, when a second dart was required, we found the time interval between darts should be less than 15 minutes. Fourteen elk shot with a second dart within 10 to 15 minutes were satisfactorily immobilized. Criteria for developing this method were based on the symptoms exhibited by drugged animals. Elk given a proper dosage would exhibit a sequence of symptoms after 3 minutes that terminated with immobilization after about 7 minutes (table 1). If at the end of 10 minutes the symptoms had not developed, we found a second shot of a lower dosage would promote immobilization. The symptoms used to judge the effectiveness of the first shot were (1) urination within 1 to 2 minutes, (2) open mouth, saliva on lips, heavy breathing at 3 to 4 minutes, and (3) muscle spasms beginning with the front shoulders in 5 to 6 minutes. Rarely would an elk exhibit none of these, yet succumb to the drug.

Of the 78 elk immobilized, five deaths occurred. One adult cow fell on a precipitous sidehill immediately after leaving the trap and died from a broken neck. Another adult cow died within 2 minutes from a 20-mg dosage; dart placement near an arterial blood supply was thought to be the cause. Three delayed mortalities, two adult cows and one yearling bull, occurred. One adult female given 20 mg appeared to have recovered after 70 minutes. She stood for 5 minutes, lay down for 23 minutes, rose, and left the trap exhibiting complete coordination. Her skeleton and collar were found 200 yards from the trap 1 year later. The other two elk died within 24 hours. An adult cow shot with two darts (each containing 20 mg) 30 minutes apart and a yearling bull shot with a 16-mg dart never regained sufficient body coordination to stand.

In 1973, the average dosage was 34.7 mg or almost double the average dosage of 19.4 mg used 1971-72. A similar experience with liquid succinylcholine chloride was reported by Craighead et al. (1973). We have no explanation for this other than the difference in efficiency of the drug between years. The latent period ranged from 2 to 21 minutes and averaged 7.1 minutes. Increasing the dosage did not significantly ($P>0.01$) affect the latent period. There were no significant ($P>0.01$) differences in the latent period between the sex and age of animals or between years. Duration of immobilization ranged from 2 to 70 minutes and averaged 24.5 minutes. There were no significant differences ($P>0.01$) for duration of immobilization between sex, age class, or years.

Of the elk immobilized, 53 percent were ranked in category II, the most desirable state; 26 percent were ranked in category III, the least desirable state; and 22 percent were ranked in category I. In this state the animal could be restrained to complete tagging, but recovery was unpredictable and sometimes untimely.

LITERATURE CITED

Castillo, J. C., and J. DeBeer
1950. The neuromuscular blocking action of succinylcholine (Diacetylocholine). Pharmacol. & Exp. Ther. 99: 458-464.

Craighead, J. J., F. C. Craighead, Jr., R. L. Ruff, and B. W. O'Gara
1973. Home ranges and activity patterns of nonmigratory elk of the Madison drainage herd as determined by biotelemetry. Wildl. Monogr. 33, 49 p.

Flook, D. R., J. R. Robertson, O. R. Hermanrude, and H. K. Buechner
1962. Succinylcholine chloride for immobilization of North American elk. J. Wildl. Manage. 26(3): 334-336.

Harper, J. A.
1965. Immobilization of Roosevelt elk by succinylcholine chloride. J. Wildl. Manage. 29(2): 339-345.

Liscinsky, S. A., G. P. Howard, and R. B. Waldeisen
1969. A new device for injecting powdered drugs. J. Wildl. Manage. 33(4): 1037-1038.

LASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

3.79 PNW-241

PNW-241 March 1975

EFFECTS OF FOREST FERTILIZATION WITH UREA ON STREAM WATER QUALITY-- QUILCENE RANGER DISTRICT, WASHINGTON

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by

Duane G. Moore, *Research Soil Scientist*

ABSTRACT

Aerial fertilization of two units on the Quilcene Ranger District of the Olympic National Forest with urea at 224 kilograms nitrogen per hectare (200 pounds nitrogen per acre) in April 1970 provided the opportunity to monitor water quality in small streams immediately adjacent to the treated areas. Applied fertilizer did reach surface streams in the form of urea-, ammonia-, and nitrate-nitrogen, but maximum concentrations measured were well below established permissible limits for public water supplies. Concentrations of urea-N never reached 1.0 part per million, ammonia-N increased only slightly above background, and the highest level of nitrate-N found was 0.121 part per million. Fertilizer nitrogen entered streams only in the form of nitrate after the first 3 weeks, and 95 percent of the total loss over 7 months occurred within the first 9 weeks after application. Fertilizer nitrogen lost during the 7-month monitoring period was about 0.25 percent of the total applied. Introduction of these small amounts of nitrogen into forest streams spread out over a period of several weeks should have little measurable impact on eutrophication.

Keywords: Fertilization (forest), water analysis, urea.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Increasing demands for wood fiber from a decreasing production base have resulted in acceleration of intensified management practices on forest lands. Use of chemical fertilizers is one of the most promising methods for increasing annual growth, and forest fertilization is rapidly becoming an operational practice in many areas of the United States. As is often the case, however, development of the practice has progressed ahead of definitive information on environmental impact.

Initial "trial and error" investigations were carried out in Europe and Australia from about 1900 to 1925 (Gessel 1969, Groman 1972); thus, the concept of fertilizing the forest is not new. However, it is only in recent years that advances in all fields of forestry and more favorable economic conditions have made operational forest fertilization feasible. Most of the forest soil fertility and tree nutrition research has occurred in the past 20 years, and large-scale forest fertilization began only in the last decade.

Within the past several years, considerable concern has been expressed over the possible toxic or eutrophic effects of fertilization of agricultural lands on water quality (Stanford, England, and Taylor 1970). This concern is being extended to all fertilizer use, including fertilization of forested watersheds. In addition to possible detrimental effects on water quality, the use of chemical fertilizers to increase growth of forest trees may affect water yield or other soil, watershed, and recreational values. Specific information is needed on these effects to accurately assess the environmental impact of forest fertilization.

In April 1970, a 113-hectare fertilization project on the Olympic National Forest provided the opportunity to monitor water quality in small streams immediately adjacent to two treated areas. Specific objectives of the monitoring were to determine (1) how much fertilizer nitrogen, if any, enters surface streams, (2) whether concentrations of nitrate, nitrite, and ammonia nitrogen reach levels considered toxic, and (3) whether the total amount of nitrogen entering the streams is sufficient to cause eutrophication in downstream impoundments.

STUDY AREA

The study area is located on the Quilcene Ranger District, Olympic National Forest, on the east side of the Olympic Peninsula in Clallam County, Washington. Project units were established on lower elevation glacial soils in areas that were in need of fertilization but where direct application of fertilizer to stream channels could be avoided. Jimmycomelately Creek, adjacent to Unit 1, drains north into Sequim Bay, and Trapper Creek (Unit 2) drains into Snow Creek which flows east and then north to Discovery Bay.

Topography of the area is a complex of glacially modified foothills, toeslopes, valley bottoms, and outwash plains. The deep glacial and colluvial soils are drained by streams that conform to dendritic patterns and range from low to moderate density (Snyder, Bush, and Wade 1969). Elevation ranges from 625 to 730 meters on Unit 1 and from 427 to 625 meters on Unit 2. Annual precipitation at the study site is estimated between 1,020 and 1,270 millimeters. Most of the precipitation occurs during the winter. Summers are dry, and streamflow often drops to less than 2.83 liters per second (l/s) in small headwater streams.

Soils of the study area have developed

in glacial till and outwash deposited during early Wisconsin time by a western lobe of the continental glacier (Snyder, Bush, and Wade 1969). Bedrock occurs at 4 meters or more beneath the soil surface. The Elwha soil series (Unit 1) and the Blyn series (Unit 2) are both Brown Podzolic soils with an effective depth of 40-100 centimeters. Surface horizon textures range from loam to silt loam while subsoil horizons are usually gravelly sandy loams. Permeability of both soils is rapid in the surface soils and moderate to slow in the subsoils.

Vegetation on 60 percent of Unit 1 was a 10-year-old stand of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Ground cover by this species was about 30 percent. Total ground cover by crop trees and subvegetation was about 85 percent. The remaining 40 percent of this unit was a dense 70-year-old stand of Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Vegetation on Unit 2 was a well-stocked, 40-year-old plantation of Douglas-fir. There was very little streamside vegetation along Jimmycomelately Creek (Unit 1) adjacent to the fertilized area. However, there was a fairly dense stand of red alder (*Alnus rubra* Bong.) along Trapper Creek adjacent to Unit 2.

METHODS

Urea fertilizer (46-percent N) was aerially applied at 492 kilograms per hectare (224 kilograms N/ha) to the Jimmycomelately unit on April 14 and to the Trapper Creek unit on April 15, 1970. Total inorganic fertilizer applied was 24,150 kilograms urea to Unit 1 (49 hectares) and 31,734 kilograms urea to Unit 2 (64 hectares). Boundaries of the units were carefully flagged and fertilizer was spread by helicopter. Half the fertilizer was applied to the units by making parallel flights, and half was applied by crossflying. The units were laid out so that fertilizer would not be applied within 60 meters of a stream. Roads and road rights-of-way were also avoided.

Monitoring stations for stream water sampling were established at points upstream and down stream from each fertilized area in late March 1970. Samples were obtained on April 1, 8, and 14 to establish background levels of urea-, ammonia-, nitrate-, and nitrite-nitrogen. Samples were collected at 2-hour intervals on the day of treatment, every 4 hours the next day, then daily through the first week. Additional samples were taken at 2, 3, 4, 6, and 9 weeks, and then every 4 weeks throughout the dry summer months. Monitoring continued until after the first fall storms, a total period of about 7 months.

Stream water samples were collected in 4-liter plastic containers, treated with mercuric chloride (40 mg/l) to prevent biological transformations of nitrogen, and shipped to the Station's Corvallis laboratory for chemical analysis. All samples were analyzed for urea-, ammonia-, nitrate-, and nitrite-nitrogen using standard methods for water analysis (Newell, Morgan, and Cundy 1967; Wood, Armstrong, and Richards 1967; Federal Water Pollution Control Administration 1969).

Jimmycomelately and Trapper Creeks were not gaged, and streamflow was estimated with a standard velocity head rod each time samples were taken. Precipitation data were from a rain gage at each sampling site during the monitoring period.

RESULTS AND DISCUSSION

Pretreatment levels of soluble nitrogen were extremely low in Jimmycomelately Creek. Nitrate-N was present at 0.001 to 0.003 parts per million (p/m) and urea-N was present in only a few samples. Ammonia-N was below the level of detection (0.004 p/m) in all pretreatment samples, and nitrite-N was not detected in any samples during the entire monitoring study. More evidence of wildlife was apparent along Trapper Creek and pretreatment samples from this stream contained an average of 0.013 p/m urea-N. Nitrate-N was present in pretreatment samples at a concentration of 0.055 p/m, possibly because of the dense stand of red alder along Trapper Creek. Ammonia- and nitrite-N were not present.

Posttreatment concentrations of nitrogen were not corrected for background. In most instances, the background level was too low for correction to influence interpretation of results. In addition, the actual concentrations of nitrogen are more important in terms of levels that may be toxic to nontarget organisms. A correction was made for background, however, in calculating the amount of applied nitrogen lost in the streams.

Concentrations of urea-, ammonia-, and nitrate-N began to increase in downstream samples from both streams shortly after application began. Loss of applied nitrogen followed the same pattern on both units (figs. 1 and 2), and the data will be discussed together. Urea-N began to increase within 3 hours after application started, reached a peak concentration of 0.71 p/m in 5 and 8 hours, and then began to decrease even though fertilization was not yet complete. The unit boundaries were laid out to avoid direct application

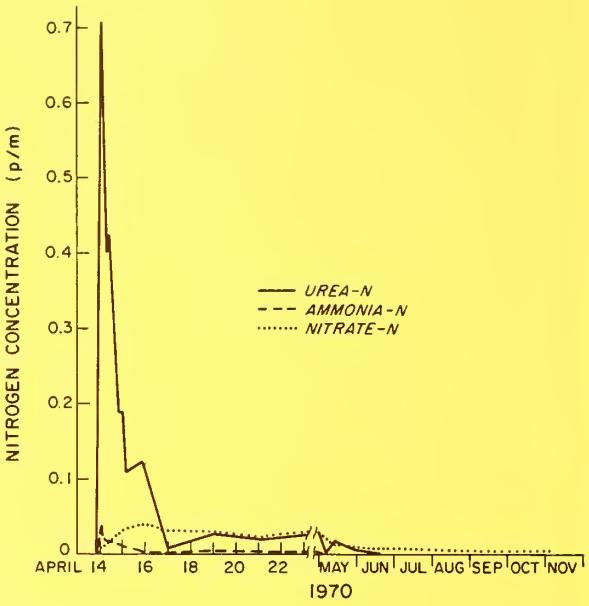

Figure 1.--Concentrations of urea-, ammonia-, and nitrate-nitrogen in streamflow following fertilization of a 49-hectare unit with 224 kilograms urea-N/ha in April 1970--Jimmycomelately Creek, Quilcene Ranger District, Olympic National Forest, Washington.

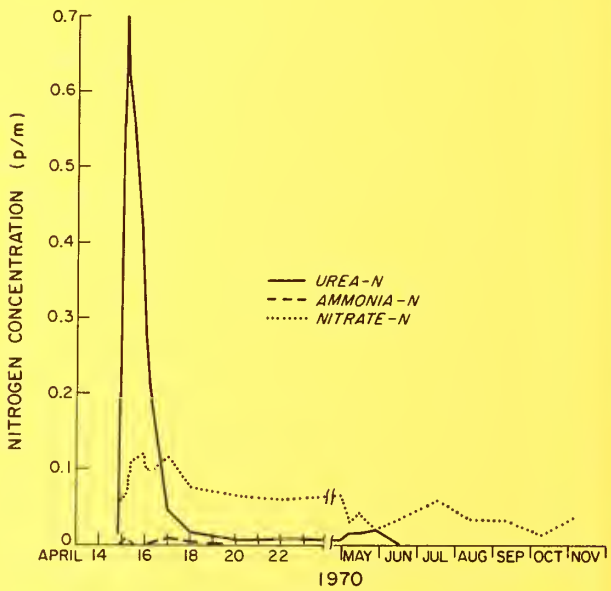

Figure 2.--Concentrations of urea-, ammonia-, and nitrate-nitrogen in streamflow following fertilization of a 64-hectare unit with 224 kilograms urea-N/ha in April 1970--Trapper Creek, Quilcene Ranger District, Olympic National Forest, Washington.

to the stream channels, but some contamination obviously occurred. Standard agricultural grade urea fertilizer was used because the large-granule forest grade was unavailable. Dust from the application was observed drifting to nontarget areas. Three consecutive samples (2-hour intervals), from the upstream station on Jimmycomelately Creek, were contaminated by drifting dust during application.

Levels of urea-N continued to decrease the day following fertilizer application and had fallen to nearly pretreatment concentrations in 4 days. Low concentrations of urea-N were found in Jimmycomelately Creek for 2 weeks. Storm activity during early May resulted in small additional losses of urea-N from both units.

Ammonia-N increased in both streams concurrent with increases in urea-N, but only small amounts of applied fertilizer were lost in this form. Peak concentrations of 0.04 and 0.01 p/m ammonia-N were measured about 6 hours after fertilizer application began. Ammonia-N returned to background levels within 1 week.

Nitrate-N began to increase slowly during the day of treatment and reached a peak concentration of 0.042 p/m in 48 hours at the downstream station on Jimmycomelately Creek. The peak concentration of 0.121 p/m nitrate-N in Trapper Creek was reached in 24 hours. When the higher background level of nitrate-N in the latter stream is considered, both streams show a comparable increase. Levels in both streams decreased slowly throughout April and May, and concentrations returned to and remained at pretreatment levels from June through November 4.

Precipitation was measured at each unit during the entire monitoring period (table 1), and at least 25 millimeters of rain fell each month from July through September. Streamflow levels dropped to less than 28 l/s, however, and little leaching of nitrate-N would be expected. Fall storm activity began in October, but nitrogen levels in both streams remained at prefertilization levels. Precipitation data for the climatological station at Quilcene indicate that over 610 millimeters of rainfall were recorded during November and December 1970, and that over 60 percent of the annual rainfall normally occurs from November through February. Data from other monitoring studies indicate

Table 1.--*Precipitation at Jimmycomelately Creek (Unit 1) and Trapper Creek (Unit 2), Quilcene Ranger District, Olympic National Forest, during the 7-month monitoring period April 8-November 4, 1970.*

Date	Unit 1	Unit 2
	--- *Millimeters* ---	
4-20	10	13
4-22	6	5
4-29	30	53
5-6	4	5
5-13	57	76
5-27	4	1/9
6-17	26	36
7-15	16	29
8-12	28	25
9-9	41	51
10-8	37	45
11-4	59	97
Total	318	444

1/ Estimated. Rain gage stolen.

that a second nitrate-N peak may have occurred (Moore 1972; Malueg, Powers, and Krawczyk 1972; Burroughs and Froehlich 1972), but it was not possible to continue sampling these streams during the winter months.

Total amounts of applied nitrogen entering the two streams during the 7-month monitoring period were estimated by averaging nitrogen concentrations and streamflow volumes between sampling dates. These estimates are summarized in tables 2 and 3. Urea-N accounted for about 36 percent of the measured loss, while an average of 60.5 percent entered the streams as nitrate-N. The total estimated loss of 21.53 kilograms nitrogen from the Jimmycomelately unit is equivalent to 0.44 kilogram N/hectare (0.20 percent of that applied). Comparable estimates for the Trapper Creek unit are slightly higher: 0.58 kilogram N/hectare, or 0.26 percent of the applied nitrogen. Perhaps of equal importance is the apparent contribution of the red alder along Trapper Creek to base level nitrogen loss rates. Red alder is known to add large amounts of nitrogen to the soil on sites where it grows (139 kilograms N/hectare/year, Franklin et al. 1968), and a portion of this added nitrogen was apparently lost in Trapper Creek. During the 7 months covered by this study, the background loss rate in Trapper Creek was about six times greater than that measured in Jimmycomelately Creek, 0.19 compared with 0.03 kilogram nitrogen per hectare.

Table 2.--*Nitrogen lost to Jimmycomelately Creek from Unit 1, Quilcene Ranger District, during the first 7 months after application of 224 kilograms N/ha*

Nitrogen form	Downstream	Control	Net loss	Percent of total loss
		Kilograms		
Urea-N	18.66	9.94	8.72	40.49
Ammonia-N	1.44	--	1.44	6.70
Nitrate-N	13.38	2.01	11.37	52.80
Total	33.48	[1/] 11.95	[2/] 21.53	--

[1/] Background loss rate from April 14 to November 4, 1970, equals 0.03 kg N/ha.

[2/] Loss of applied nitrogen, 21.53 kilograms from 49 hectares, approximately 0.44 kg N/ha (0.20 percent of that applied).

Table 3.--*Nitrogen lost to Trapper Creek from Unit 2, Quilcene Ranger District, during the first 7 months after application of 224 kilograms N/ha*

Nitrogen form	Downstream	Control	Net loss	Percent of total loss
		Kilograms		
Urea-N	40.83	29.10	11.73	31.26
Ammonia-N	0.22	--	0.22	0.58
Nitrate-N	104.30	78.73	25.57	68.16
Total	145.35	[1/] 107.83	[2/] 37.52	--

[1/] Background loss rate from April 15 to November 4, 1970, equals 0.19 kg N/ha.

[2/] Loss of applied nitrogen, 37.52 kilograms from 64 hectares, approximately 0.58 kg N/ha (0.26 percent of that applied).

SUMMARY AND CONCLUSIONS

Streams flowing adjacent to two small forest fertilization projects in the Quilcene Ranger District were monitored for possible impact on water quality over a period of 7 months following fertilization at 224 kilograms urea-N per hectare. Unit boundaries were laid out to avoid direct application to stream channels, but some contamination did occur during application due to minor problems with drifting fertilizer dust. Direct application of urea prills to streams also occurred but was minimal; concentrations of urea-N never reached 1.0 p/m at downstream monitoring stations. In other fertilization projects where no attempt was made to avoid streams within the treated unit, concentrations of urea-N in stream water have ranged from 1.39 to 44.4 p/m (Thut 1970; McCall 1970; Moore 1970; Burroughs and Froehlich 1972; Malueg, Powers, and Krawczyk 1972).

Applied fertilizer entered surface streams in the form of urea-, ammonia-, and nitrate-N, but maximum concentrations measured never approached levels known to be toxic (10 mg/l N as nitrate- plus nitrite-N is recommended maximum limit for public water supplies (Federal Water Pollution Control Administration 1968)). Applied nutrient lost during the monitoring period was very small, about 0.25 percent of the total fertilizer nitrogen applied. Losses in the form of ammonia-N occurred in the first 4 days. Nitrogen losses in the form of urea were 70 to 90 percent complete in 1 week, but small losses continued for up to 3 weeks. Virtually all of the fertilizer nitrogen entering the streams after the first 3 weeks was measured as nitrate, and this form of nitrogen accounted for 53 and 68 percent of the total measured loss of applied nutrient from the two units monitored. Over 95 percent of the total loss for the

first 7 months occurred within the first 9 weeks after fertilizer application.

Monitoring of the two streams was discontinued after the November sampling because of inaccessibility of the project area during winter months. It is possible that additional losses of applied nitrogen in the form of nitrate could occur during winter storms. However, peak concentrations would probably be lower than those measured just after application because of the dilution effect of higher streamflow. Low soil and water temperatures during the winter months greatly retard nitrification; and as soon as any accumulated nitrate-nitrogen is leached out of the soil, concentrations in the stream would drop rapidly to pretreatment levels. The present study did not offer the opportunity to observe any effects of increased nitrogen on eutrophication in downstream impoundments, but the small amounts of nitrogen entering the stream over several weeks would not be expected to have any measurable impact.

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LITERATURE CITED

Burroughs, Edward R., Jr., and Henry A. Froehlich
1972. Effects of forest fertilization on water quality in two small Oregon watersheds. U.S. Dep. Inter. Bur. Land Manage. Tech. Note, 8 p. Portland, Oreg.

Federal Water Pollution Control Administration
1968. Water quality criteria. 234 p. U. S. Dep. Inter.

———
1969. F. W. P. C. A. methods for chemical analysis of water and wastes. 280 p. U. S. Dep. Inter.

Franklin, Jerry F., C. T. Dyrness, Duane G. Moore, and Robert F. Tarrant
1968. Chemical soil properties under coastal Oregon stands of alder and conifers. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.). Northwest Sci. Assoc. 40th Annu. Meet. Symp. Proc. 1967: 157-172.

Gessel, Stanley P.
1969. Introduction to forest fertilization in North America. For. Ind. 96(10):26-28.

Groman, William A.
1972. Forest fertilization: A state-of-the-art review and description of environmental effects. Environ. Prot. Technol. Ser. EPA-R2-016, 57 p. Pac. Northwest Water Lab. Environ. Prot. Agency, Corvallis, Oreg.

McCall, Merley
1970. The effects of aerial forest fertilization on water quality for two streams in the Capitol Forest. 20 p. State Wash. Dep. Ecol., Olympia, Wash.

Malueg, K. W., C. F. Powers, and D. F. Krawczyk
1972. Effects of aerial forest fertilization with urea pellets on nitrogen levels in a mountain stream. Northwest Sci. 46(1):52-58.

Moore, D. G.
1970. Forest fertilization and water quality in the Pacific Northwest. Am. Soc. Agron. Abstr. 1970: 160-161.

Moore, Duane G.
1972. Fertilization and water quality. *In* West. Reforestation Coord. Comm. Proc. 1971:28-31. West. For. & Conserv. Assoc.

Newell, B. S., B. Morgan, and J. Cundy
1967. The determination of urea in sea water. J. Mar. Res. 25(2):201-202.

Snyder, Robert V., George S. Bush, Jr., and John M. Wade
1969. Olympic National Forest soil resource management survey report. 158 p. USDA For. Serv., Pac. Northwest Reg., Portland, Oreg.

Stanford, G., C. B. England, and A. W. Taylor
1970. Fertilizer use and water quality. USDA Agric. Res. Serv. 41-168, 19 p.

Thut, Rudolph N.
1970. Effects of forest fertilization on surface waters. Proj. No. 045-0073, 29 p. Weyerhaeuser Co. Res. Div., Longview, Wash.

Wood, E. D., F. A. J. Armstrong, and F. A. Richards
1967. Determination of nitrate in sea water by cadmium-copper reduction to nitrite. J. Mar. Biol. Assoc. U. K. 47:23-31.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
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ADDITIONAL RELEASES OF LARCH CASEBEARER PARASITES FOR BIOLOGICAL CONTROL IN THE WESTERN UNITED STATES

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ABSTRACT

Additional Chrysocharis laricinellae[6] *and four new parasites,* Necremnus metalarus,[6] Elachertus argissa,[6] Dicladocerus "*A*",[6] *and* Diadegma laricinella,[7] *were released for biological control of the larch casebearer in Washington, Idaho, and Montana.*

KEYWORDS: *Biological control (-forest pests, larch casebearer,* Coleophora laricella, Chrysocharis laricinellae, Necremnus metalarus, Elachertus argissa, Dicladocerus "*A*", Diadegma laricinella.

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[6]Hymenoptera: Eulophidae.
[7]Hymenoptera: Ichneumonidae.

INTRODUCTION

The larch casebearer, *Coleophora laricella* (Hbn.), is a minor pest of larch in Europe. It was inadvertently introduced into eastern North America, where the subsequent defoliation of eastern larch (*Larix laricina* (Du Roi) Koch.) prompted a parasite introduction program in the 1930's (Dowden 1962, McGugan and Coppel 1962). Two of the five species released, the braconid, *Agathis pumila* (Ratz.), and the eulophid, *Chrysocharis laricinellae* (Ratz.), became established. Casebearer populations dropped considerably following the establishment of these parasites and have generally remained low enough to cause little or no concern, making it an example of successful biological control (Turnbull and Chant 1961, DeBach 1964).

Now that the casebearer has invaded western larch (*Larix occidentalis* Nutt.) stands in the Western United States, attempts are being made to extend biological control to this infestation. *A. pumila* was introduced in 1960 (Denton 1972), and *C. laricinellae* and *Dicladocerus westwoodii* Westw. were released in 1972 (Ryan and Denton 1973).[8] Additional releases of *C. laricinellae* from several sources were made in 1973 and 1974 and four new species were released in 1974. The purpose of this note is to record details of the sources of these populations, dates, and locations of these new releases.

ACQUISITION AND IDENTITY OF RELEASED MATERIAL

All parasites originated from collections of *Coleophora laricella* (Hbn.) (Lepidoptera: Coleophoridae) in Europe or Wisconsin or *C. longisignella* Moriuti in Japan taken from larch (*Larix*), the species of larch depending on the locality. Parasites were identified by C. M. Yoshimoto, Canadian Forestry Service, Department of Environment, Ottawa, and B. D. Burkes[9] and R. W. Carlson, U.S. National Museum, Washington, D.C. Voucher specimens are available at the U.S. National Museum or the Beneficial Insect Research Laboratory, Newark, Delaware.

The *Chrysocharis laricinellae* material which was released originated from several different localities. At the time of their collection there was some uncertainty as to how many species of *Chrysocharis* parasitize the larch casebearer. Stock known as *C. novellus* (Jagsch 1973) was obtained from Austria; stock obtained from Sweden was known

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[8]Both *C. laricinellae* and *D. westwoodii* are reported to be present in western larch stands. See Ryan et al. (1974) and Miller and Finlayson (1974).

[9]Retired.

as *C. nitetis* (Eidmann 1965). *C. laricinellae* was also obtained from England and from Wisconsin. In view of the taxonomic uncertainties, populations from the four source locations were considered different and were cultured and released separately. However, subsequent biosystematic study has since shown these to be conspecific (Ryan and Yoshimoto, in press).

Parasites from the Tyrolian and Styrian Alps of Austria and North Tirol of northern Italy were obtained from 1972 to 1974 through the cooperation of H. Pschorn-Walcher of the European Station, Commonwealth Institute of Biological Control, Delemont, Switzerland, and collectors Jagsch, Blumel, and Altenhofer. Collections in England in May of 1972 were made by personnel of the Forest Research Station, Farnham, at Staple Edge, Edgehill, and Crabtree Hill, all near Cinderford, Gloucestershire. H. Eidmann, Royal College of Forestry, Stockholm, and the Stockholm Biological Laboratory made collections in Uppland, Sweden, in March and April of 1973. Collections in northern Wisconsin in May and June of 1972 were made by H. C. Coppel and J. W. Mertins, University of Wisconsin, Madison. Collections in the Nagano and Gifu prefectures of central Honshu, Japan, were made in May and June of 1974 by N. Morimoto, Shinshu University, Ina, and K. Kanamitsu, Tokyo University, respectively.

Adult parasite shipments from abroad or infested material from which parasites subsequently emerged in quarantine were received at Belleville, Ontario, by J. S. Kelleher and G. D. Williamson, Agriculture Canada, Ottawa; or at Moorestown, New Jersey, or Newark, Delaware, by W. H. Day and L. R. Ertle, Beneficial Insect Research Laboratory, Newark, Delaware.

LOCATION, TIMING, AND SIZE OF RELEASES

Details of the releases are presented in table 1. Releases were timed to coincide with the presence of susceptible host stages. *Diadegma laricinella* (Strobl) parasitizes needlemining larvae, whereas *C. laricinellae*, *Necremnus metalarus* (Walker), *Elachertus argissa* (Walker), and *Dicladocerus* "A" attack casebearing larvae. Although highly dependent upon elevation, casebearing larvae were actively feeding from late April until early June and again from mid-September through October.

Parasites were released on study plots on which data on host density and parasitization are being taken by the several agencies cooperating in the work. Thus, evaluation of the introductions will be available.

Table 1.--Releases of *Chrysocharis laricinellae*, *Necremnus metalarus*, *Elachertus argissa*, *Dicladocerus* "A," and *Diadegma laricinella* in Washington, Idaho, and Montana, 1973-74

Liberation site	Date of release	Number released		
		Male	Female	Total
Chrysocharis laricinellae (Ratz.) (Hymenoptera: Eulophidae)				
Idaho[1]				
U.S. Hwy. 95,25 mi N. Moscow 47°02' N. 116°52' W.	Apr. 25, 1973	192	433	625
	May 2, 1973	75	136	211
	May 5, 1973	62	111	173
	May 16, 1973	127	203	330
	May 30, 1973	160	220	380
	Sept. 11, 1973	33	172	205
	Oct. 5, 1973	140	67	207
4.6 mi N. Troy 46°47' N. 116°48' W.	May 4, 1974	263	244	507
5.6 mi N. Troy 46°48' N. 116°47' W.	May 16, 1974	151	154	305
6 mi N. Troy 46°48'N. 116°47' W.	May 22, 1974	147	159	306
Lochsa River, Eagle Mountain Pack Bridge 62.2 mi E. Kooskia 46°26' N. 115°8' W.	May 30, 1974	147	154	301
3.4 mi E. Bovill 46°51' N. 116°20' W.	Sept. 27, 1974	33	276	309
Montana[2]				
4 mi N. Evaro 47°05' N. 114°04' W.	May 2, 1973	283	403	686
	May 11, 1973	81	116	197
	May 18, 1973	122	134	256
	May 23, 1973	93	102	195
	May 16, 1974	196	219	415
	May 31, 1974	80	92	172
	June 7, 1974	63	123	186
Washington				
Colville Indian Reservation, E. Round Lake[3] 48°17' N. 118°18' W.	April 27, 1973	238	472	710
	May 9, 1973	185	159	344
	May 17, 1973	85	89	174
	May 24, 1973	179	72	251
	May 7, 1974	187	230	417
	May 24, 1974	131	115	246
	May 31, 1974	89	78	167
	Sept. 26, 1974	1	112	113

See footnotes at end of table.

Table 1.--Releases of *Chrysocharis laricinellae*, *Necremnus metalarus*, *Elachertus argissa*, *Dicladocerus* "A," and *Diadegma laricinella* in Washington, Idaho, and Montana, 1973-74--continued

Liberation site	Date of release	Number released		
		Male	Female	Total
Chrysocharis laricinellae (Ratz.) (Hymenoptera: Eulophidae) (continued)				
Charley Creek, 15 mi S. Pomeroy[4] 46°15' N. 117°30' W.	May 11, 1973	195	58	253
	Sept. 25, 1973	119	81	200
	Oct. 10, 1973	292	182	474
	May 10, 1974	659	573	1,232
	May 23, 1974	108	131	239
	May 30, 1974	155	185	340
	June 7, 1974	123	157	280
	Sept. 20, 1974	122	192	314
	Sept. 25, 1974	143	124	267
Necremnus metalarus (Walk.) (Hymenoptera: Eulophidae)[1]				
Idaho				
4.6 mi N. Troy 46°47' N. 116°48' W.	May 4, 1974	3	409	412
5.6 mi N. Troy 46°48' N. 116°47' W.	May 16, 1974	0	145	145
6 mi N. Troy 46°48' N. 116°47' W.	May 22, 1974	1	139	140
Lochsa River, Eagle Mountain Pack Bridge 62.2 mi E. Kooskia 46°26' N. 115°8' W.	May 30, 1974	0	135	135
3.4 mi N. Bovill 46°51' N. 116°20' W.	Sept. 27, 1974	6	825	831
	Oct. 9, 1974	5	386	391
Montana				
4 mi N. Evaro 47°05' N. 114°04' W.	May 16, 1974	1	406	407
	May 31, 1974	0	175	175
	June 7, 1974	1	162	163
	Sept. 24, 1974	1	275	275
	Oct. 3, 1974	0	211	211
Washington				
Colville Indian Reservation, E. Round Lake 48°17' N. 118°18' W.	May 7, 1974	1	378	379
	May 24, 1974	0	124	124
	May 31, 1974	0	124	124
	Sept. 26, 1974	0	357	357
	Oct. 1, 1974	0	238	238

See footnotes at end of table.

Table 1.--Releases of *Chrysocharis laricinellae*, *Necremnus metalarus*, *Elachertus argissa*, *Dicladocerus* "A," and *Diadegma laricinella* in Washington, Idaho, and Montana, 1973-74--continued

Liberation site	Date of release	Number released		
		Male	Female	Total
Necremnus metalarus (Walk.) (Hymenoptera: Eulophidae)[1] (continued)				
Charley Creek, 15 mi S. Pomeroy	May 10, 1974	1	445	446
46°15' N. 117°30' W.	May 23, 1974	1	139	140
	May 30, 1974	0	95	95
	June 7, 1974	0	92	92
	Sept. 20, 1974	0	116	116
	Sept. 25, 1974	0	173	173
	Oct. 4, 1974	0	135	135
Elachertus argissa (Walk.) (Hymenoptera: Eulophidae)[1]				
Idaho				
3.4 mi E. Bovill	Sept. 27, 1974	10	141	151
46°51' N. 116°20' W.	Oct. 9, 1974	3	74	77
	Oct. 18, 1974	12	51	63
Montana				
4 mi N. Evaro	Sept. 24, 1974	7	105	112
47°05' N. 114°04' W.				
Washington				
Colville Indian Reservation, E. Round Lake	Sept. 26, 1974	7	102	109
48°17' N. 118°18' W.				
Charley Creek, 15 mi S. Pomeroy	Sept. 20, 1974	8	81	89
46°15' N. 117°30' W.	Sept. 25, 1974	2	43	45
	Oct. 4, 1974	1	31	32
Dicladocerus "A" (Hymenoptera: Eulophidae)[5]				
Idaho				
3.4 mi E. Bovill	Sept. 27, 1974	0	65	65
46°53' N. 116°20' W.				
Diadegma laricinella (Strobl) (Hymenoptera: Ichneumonidae)[6]				
Idaho				
4.6 mi N. Troy	July 23, 1974	0	10	10
46°47' N. 116°48' W.				

[1]Parasite strain originated in Austria-northern Italy.
[2]Parasite strain originated in England.
[3]Parasite strain recolonized from Wisconsin.
[4]Parasite strain originated in Sweden.
[5]Adults reared from material collected in Japan. The species is believed distinct from *Dicladocerus westwoodii* Westw. and *Dicladocerus* spp. already present (see Miller and Finlayson 1974).
[6]Adults reared from material collected in Austria-northern Italy.

LITERATURE CITED

Denton, Robert E.
1972. Establishment of *Agathis pumila* (Ratz.) for control of larch casebearer, and notes on native parasitism and predation in Idaho. USDA For. Serv. Res. Note INT-164, 6 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

DeBach, Paul
1964. Successes, trends, and future possibilities. *In* P. DeBach (ed.), Biological control of insect pests and weeds, p. 673-713. Chapman and Hall, London.

Dowden, Philip B.
1962. Parasites and predators of forest insects liberated in the United States through 1960. U.S. Dep. Agric. Agric. Handb. 226, 70 p. Washington, D.C.

Eidmann, Hubertus H.
1965. Ökologische und physiologische Studien über die Lärchenminiermotte, *Coleophora laricella* Hbn. Stud. For. Suec. Nr. 32, 222 p.

Jagsch, Albert
1973. Populationsdynamik und Parasitenkomplex der Lärchenminiermotte, *Coleophora laricella* Hbn., im natürlichen Verbreitungsgebiet der Europäischen Lärche, *Larix decidua* Mill. Z. Angew. Entomol. 73: 1-42.

McGugan, B. M., and H. C. Coppel
1962. Biological control of forest insects--1910-1958. *In* A review of the biological control attempts against insects and weeds in Canada, Part II, p. 35-216. Tech. Commun. No. 2. Commonw. Inst. Biol. Control. Commonw. Agric. Bur., Farnham Royal, England.

Miller, G. E., and T. Finlayson
1974. Native parasites of the larch casebearer, *Coleophora laricella* (Lepidoptera: Coleophoridae), in the West Kootenay area of British Columbia. J. Entomol. Soc. B.C. 71: 14-21.

Ryan, R. B., W. E. Bousfield, G. E. Miller, and T. Finlayson
1974. Presence of *Chrysocharis laricinellae*, a parasite of the larch casebearer, in the Pacific Northwest. J. Econ. Entomol. 67: 805.

Ryan, R. B., and R. E. Denton
1973. Initial releases of *Chrysocharis laricinellae* and *Dicladocerus westwoodii* for biological control of the larch casebearer in the Western United States. USDA For. Serv. Res. Note PNW-200, 4 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Ryan, R. B., and C. M. Yoshimoto
(in press) Laboratory crossings with different sources of the larch casebearer parasite, *Chrysocharis laricinellae* (Ratz.) (Hymenoptera: Eulophidae). Can. Entomol.

Turnbull, A. L., and D. A. Chant
1961. The practice and theory of biological control of insects in Canada. Can. J. Zool. 39: 697-753.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

3.79 TNW-243

PNW-243 March 1975

SOIL MOISTURE DEPLETION AND GROWTH RATES AFTER THINNING PONDEROSA PINE

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ABSTRACT

In 1967, a study was started near Baker, Oregon, to compare soil moisture depletion and growth rates on unthinned plots with other plots thinned to spacings of 12, 15, 18, and 21 feet (3.7, 4.5, 5.5, and 6.4 m). The first summer after thinning, soil moisture depletion was 9.3, 9.0, and 6.1 inches (23.6, 22.9, and 15.5 cm) in the control, lightly thinned, and heavily thinned plots, respectively. Depletion from heavily thinned plots averaged 3.3 inches (8.4 cm) less than from control plots during the first three summers after treatment. Light thinning had no measurable effect on moisture depletion. Growth was greatest on the stand thinned to 15-foot (4.6-m) spacing.

KEYWORDS: Soil moisture, thinnings, ponderosa pine, *Pinus ponderosa*.

In 1967 a study was begun on moisture input and soil moisture depletion after ponderosa pine (*Pinus ponderosa* Laws.) was thinned. The purpose of this paper is to present the soil moisture and related results along with some tree growth data.

THE STUDY AREA

The study area is on the Wallowa-Whitman National Forest about 15 miles (24 km) southwest of Baker, Oregon (fig. 1). Elevations of the

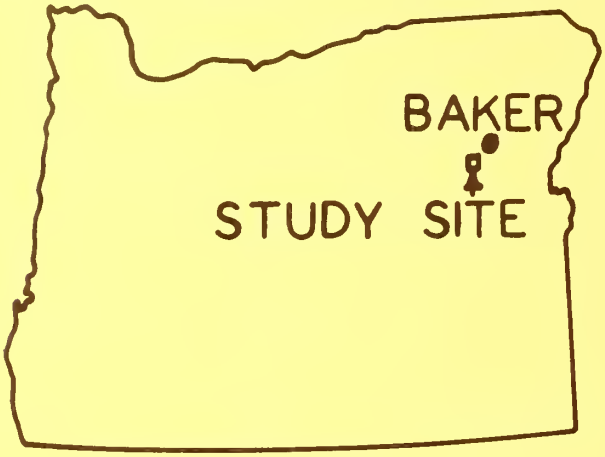

Figure 1.--The study area is located about 15 miles (24 km) southwest of Baker, Oregon.

plots range from 4,500 to 4,800 feet (1372 to 1463 m). The aspect is generally southwest on slopes of inclination less than 20 percent. The vegetation is predominantly ponderosa pine which was established after heavy logging around 1900. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western larch (*Larix occidentalis* Nutt.) are minor components of the overstory. Because of the dense canopy, understory vegetation was scarce before thinning. After thinning, native grasses such as elk sedge (*Carex geyeri* Bott.) and pinegrass (*Calamagrostis rubescens* Buckl.) became prominent.

Stand age at the time of thinning was about 50 years, height of dominants averaged 40 feet (12.2 m), and growth rates averaged only about 0.05 inch (1.27 mm) per year. Sartwell and Dolph[1/] estimated site index at 65 and site class as V.

METHODS

The study design for evaluating thinning effects consisted of 10 plots, each containing about 25 acres (10.1 ha). Each of the following intensities was assigned to two plots: (1) no thinning, (2) remove all suppressed trees, (3) remove all suppressed and intermediate trees, (4) remove all suppressed, intermediate, and poorly placed codominant trees, and (5) remove all except the dominant and codominant trees.

[1/] Charles Sartwell and Robert E. Dolph, Jr. Silvicultural and direct control of mountain pine beetle in second-growth ponderosa pine. Paper being prepared.

Average spacing between residual trees was 12, 15, 18, and 21 feet (3.7, 4.6, 5.5, and 6.4 m) for treatments 2, 3, 4, and 5, respectively. Soil moisture and snow measurements were made on pairs of plots receiving treatments 1, 2, and 5.

On each plot receiving treatments 1, 2, or 5, 25 equally spaced sample points were chosen for snow sampling. Then five of these points were randomly selected for soil moisture measurements. Soil moisture access tubes were installed as deeply as possible during the summer of 1967--right after the thinnings were completed. Of the 30 access tubes installed (6 plots with 5 tubes each), 8 were installed to 6 feet (1.8 m), 14 to 5 feet (1.5 m), 7 to 4 feet (1.2 m), and 1 to 3 feet (0.9 m).

Snow depth and density data were collected starting about February 1 when peak accumulation usually occurred and at approximately 2-week intervals until complete snowmelt. Soil moisture measurements were made with neutron-scattering instruments at 1-foot (30-cm) intervals in the profile, beginning at the 6-inch (15-cm) level. The first reading each season was made as soon as possible after snowmelt and at approximately monthly intervals through the summer. The final reading each year was in the latter part of September when annual soil moisture levels are lowest. Precipitation was measured with one storage gage between November 1968 and October 1971.

Soil moisture depletion was analyzed using the methods of Barrett (1970) and Sartz (1972). In this analysis, the difference in moisture content held by the profile between the first and last observation each summer was taken as the response variable. This value is not the same as total moisture use because some precipitation falls during the summer months and part of the moisture held in the spring is lost by drainage. A major weakness of the method is that an indicated depletion difference between thinning intensity is logically underestimated because drainage will be greater from the profile which retains the most water. Therefore, moisture depletion results presented here should be considered as qualitatively correct, but perhaps not exact quantitatively. A more rigorous statistical analysis was not possible because of the spatial variability of total moisture content and the lack of sufficient sites to adequately define mean values. Moisture changes between dates, as used here, are less variable between sites than total moisture contents; thus fewer sampling points are needed for a given degree of accuracy (Hewlett et al. 1963).

Basal area was measured on all plots just after thinning in 1967 and again in 1972. Growth rate was measured on cores taken from five dominant or codominant trees in each of the unthinned, lightly thinned, and heavily thinned plots at the end of the 1973 growing season.

RESULTS AND DISCUSSION

Although precipitation measurements are for a short time period, they correlate well with records from a station near Baker ($R^2 = 0.88$) where measurements began more than 80 years ago. Precipitation at the Baker station was slightly below the long-term average in 1969, 40 percent above average in 1970, and 23 percent above average in 1971. Assuming that the same relationships hold for the study area, average annual precipitation there is about 18 inches (46 cm). The summer months of July through September are driest with 12 percent of the annual total, while November through January are wettest with more than 30 percent.

Snow pack data presented in table 1 were collected between February 3 and 6 of each year--the approximate time of maximum annual snow accumulation. Although the snow pack was not very deep during the study, there

Table 1.--*Average snow depth and water content (w.c.) at peak snow pack*

Treatment	1968		1969		1970		1971	
	Depth	w.c.	Depth	w.c.	Depth	w.c.	Depth	w.c.
	Inches (centimeters)							
Control	10.0 (25.4)	2.45 (6.22)	20.5 (52.1)	3.40 (8.64)	12.0 (30.5)	3.50 (8.89)	8.6 (21.8)	2.70 (6.86)
Lightly thinned	13.0 (33.0)	3.25 (8.26)	24.0 (61.0)	4.80 (12.19)	15.5 (39.4)	4.30 (10.92)	11.9 (30.23)	3.50 (8.89)
Heavily thinned	14.0 (35.6)	3.65 (9.27)	27.0 (68.6)	5.20 (13.21)	19.1 (48.5)	5.10 (12.95)	15.2 (38.6)	4.40 (11.18)

is a direct relationship between snow depth and thinning intensity as well as between water content and thinning intensity. Snow disappeared from all plots at about the same time each year. Several studies of snow accumulation after timber harvest in the Western States have been reported, and the results generally agree with results in table 1; i.e., snow accumulation was deepest in the heavily thinned stand and least in the unthinned control. However, there is disagreement as to whether the observed results are caused by redistribution of snow by wind or whether snow interception from the natural forest is significantly greater than from the thinned or harvested plots (Hoover 1971). Since wind measurements are not available for the present study, it is not possible to determine a cause and effect relationship.

The soil profile averaged about 5 feet (1.5 m) deep. The soils are fine textured and have a high moisture retention, even at 15-bar suction (table 2).

Moisture lost from the profile between spring and autumn varied

Table 2.--*Physical characteristics of soil*

Depth interval (cm)	Sand	Silt	Clay	Bulk density	pH	Moisture retention at (bars)				
						0.2	0.5	1.0	5.0	15.0
	- - - *Percent* - - -			*g/cm*^{3}		- - - - *Percent by volume* - - - -				
7-30	34	51	15	1.26	4.60	35.0	27.5	23.0	13.5	12.5
30-60	35	20	45	1.69	4.35	46.5	36.5	34.0	23.5	20.5
60-150	50	18	32	1.87	4.50	43.5	38.0	34.0	24.0	22.5

considerably between sites. For example, in the heavily thinned plots, moisture loss for 1968 varied from 2.5 to 10.6 inches (6.4 to 26.9 cm), averaging 6.1 inches (15.5 cm). In the control plots, loss values varied from 5.6 to 14.4 inches (14.2 to 36.6 cm), averaging 9.2 inches (23.4 cm). There was no significant correlation between moisture loss at a measurement site and the distance from the site to the nearest tree. The lower loss from the heavily thinned plots is attributed to reduced evapotranspiration losses. Moisture losses from the control plots exceeded losses from the heavily thinned plots by 3.1, 4.5, and 2.4 inches (7.9, 11.4, and 6.1 cm) during the first, second, and third year after treatments, respectively (fig. 2). These values were significantly

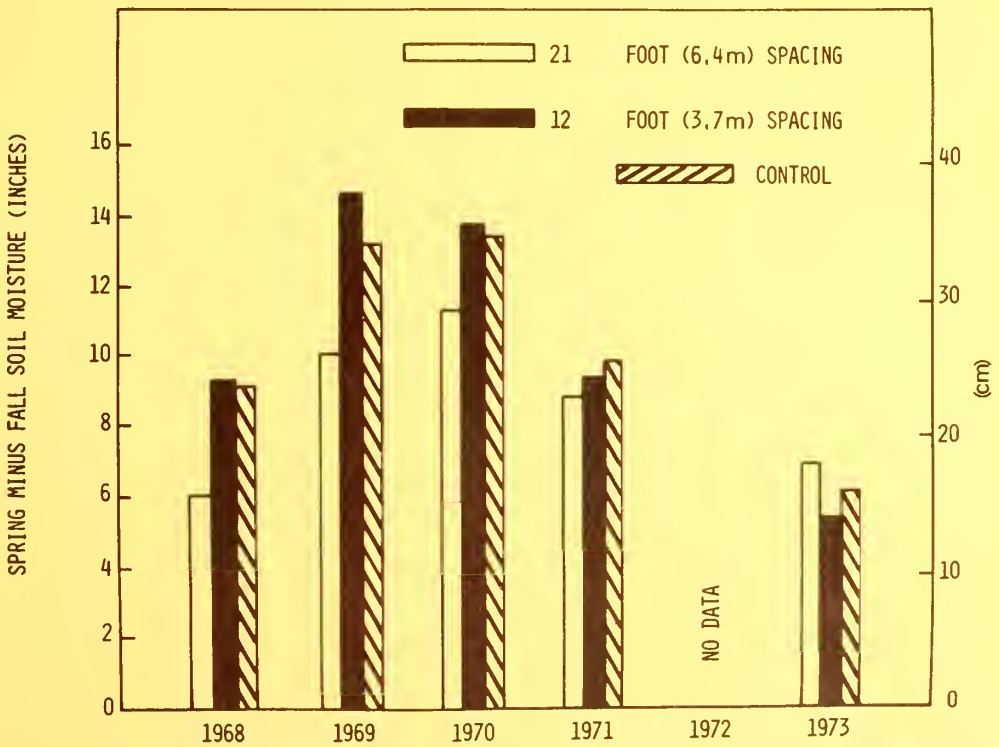

Figure 2.--Difference in soil moisture held by the profile in spring and fall as a function of thinning intensity and years after thinning.

greater than zero at the 0.05 level in a one-way analysis of variance test. Although moisture depletion from the lightly thinned plots was slightly less than from the control, the difference is not significantly different from zero at even the 0.10 level.

It is somewhat surprising that results presented in figure 2 indicate no significant difference in moisture depletion from either treatment during the fourth and sixth years after thinning. One plausible explanation is that after 3 years, the remaining trees were able to extend their roots and crowns into spaces formerly occupied by the cut trees. Consequently, water use by these trees was much greater than before. Tree crowns are definitely wider and thicker in the heavily thinned plots, but no attempt was made to test the idea that tree roots invaded the unoccupied spaces. Reproduction and other low vegetation would be expected to decrease water supplies in the thinned areas. Although reproduction is scarce, figure 3 shows native grasses are quite thick along the soil moisture transect, and they probably significantly influenced the moisture regime.

Figure 3.--This photograph of a plot thinnned to 21-foot (6.4-m) spacing was made 6 years after treatments. Note the dense grass cover along the soil moisture sampling transects.

Changes in basal area between late summer 1967 and 1972 are shown in table 3. It appears that optimum spacing for tree growth is 15 feet (4.6 m), at least for the first 5 years. The wider spacing may be more desirable over a longer period, however.

Table 3.--*Basal area changes during the 5 years after thinning*[1/]

Average spacing treatment	Basal area		
	1967	1972	Change
	Square feet per acre (m^2/ha)		
Unthinned	173.2 (40.2)	152.5 (35.4)	-20.7 (-4.8)
12 ft (3.66 m)	116.8 (27.1)	113.5 (26.3)	-3.3 (-0.8)
15 ft (4.57 m)	85.8 (19.9)	89.0 (20.6)	+3.2 (+0.7)
18 ft (5.49 m)	61.8 (14.3)	64.8 (15.0)	+3.0 (+0.7)
21 ft (6.40 m)	35.0 (8.1)	37.2 (8.6)	+2.2 (+0.5)

[1/] These data, collected in late summer of both years, were provided by Charles Sartwell, Entomologist, at Forestry Sciences Laboratory, Corvallis, Oregon.

Growth was also measured on 10 cores from dominant trees in treatments 1, 2, and 5. Growth rate within the heavily thinned plot accelerated sharply from age 50 to 55 years (after treatment) and trees in the lightly thinned and control plots followed trends similar to each other (fig. 4). In the control, lightly thinned, and heavily thinned stands, 5-year diameter increment was 0.25, 0.35, and 1.1 inch (6.4, 8.9, and 27.9 mm), respectively. The obvious conclusion is that these stagnant stands must be thinned to a spacing greater than 12 feet (3.7 m) in order to stimulate radial growth rate.

Sartwell and Dolph (see footnote 1) concluded that the light thinning had little influence on mountain pine beetle (*Dendroctonus ponderosa*) activity, but they reasoned that light thinning may be beneficial to younger stands.

These soil moisture and diameter growth results are similar to those reported by Barrett (1970) for his thinning study in ponderosa pine near Bend, Oregon. Although Barrett's main objective was growth rate response, he also measured soil moisture with sampling points located in the center of the geometric figure formed by four trees. Since the sampling points in the present study were randomly located, the studies are not strictly comparable. However, it is worth noting that Barrett's results still showed decreased moisture use in thinned stands after 8 years, but in the present study no treatment effect could be detected 3 years after the heavy thinning. The dense ground cover along the soil moisture transects (fig. 3) could be a factor in this different response.

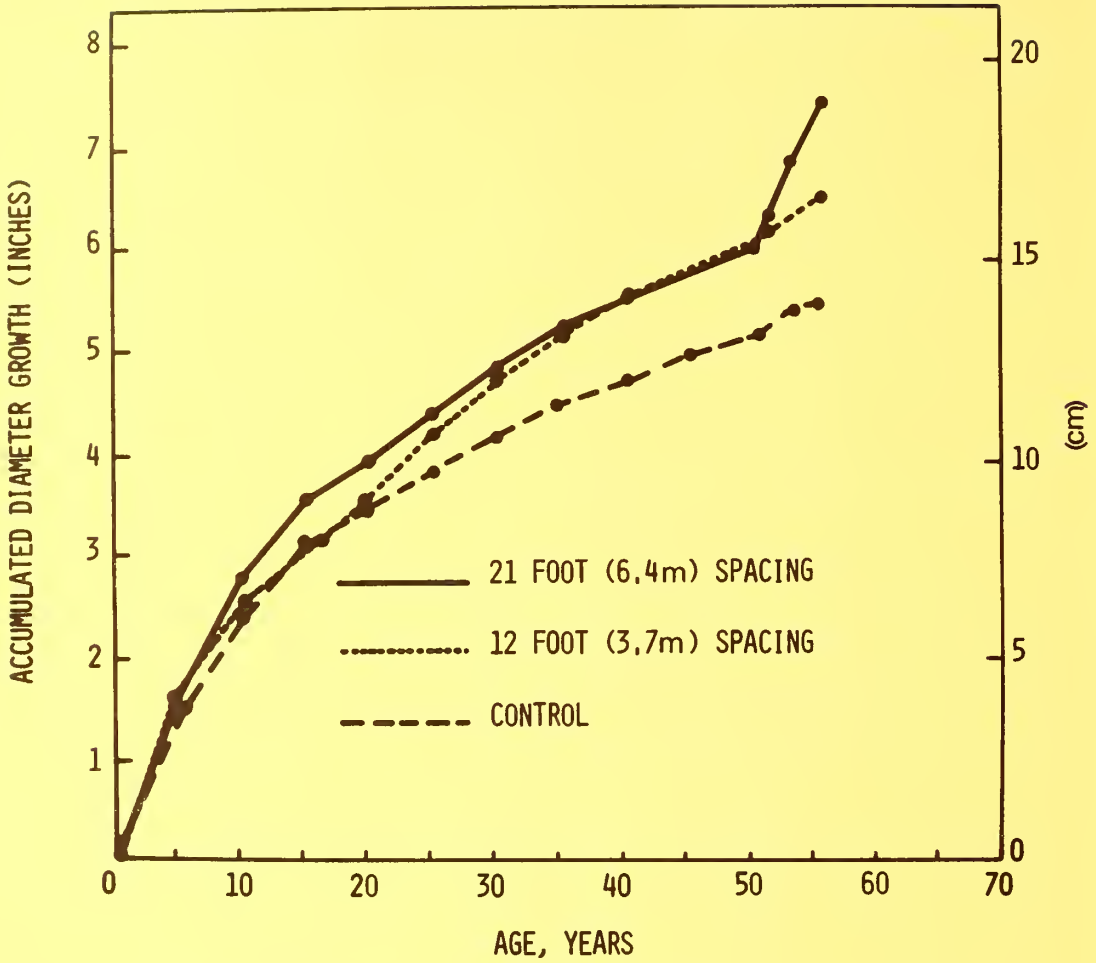

Figure 4.--Accumulated diameter growth of stands receiving light thinning, heavy thinning, and no thinning.

CONCLUSION

This study, while not providing definitive answers to the questions of thinning effects on moisture depletion and growth response, provides clues to these effects. Heavy thinning produced temporary reductions in moisture depletion during summer months and accelerated growth rates on the residual stems. Approximately 25,000 acres (10 125 ha) of stagnant ponderosa pine forest east of the Cascade Range in Washington and Oregon are being thinned each year.[2/] If the results of this study are representative, approximately 20,000 acre-feet (2.47×10^7 m^3) less water are used

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[2/] Personal communication with Reforestation and Stand Improvement Specialists, U.S. Forest Service, Region 6, Portland, Oregon.

by trees in thinnned areas each year. It was not possible to determine the fate of the extra moisture held by the soil profile after treatment, but the thinned stands are too scattered to significantly affect surface water supplies. The higher moisture levels in the soil, along with additional sunlight, will stimulate growth of grasses and forbs as well as residual trees. According to Sartwell and Dolph (see footnote 1), tree mortality by mountain pine beetle was reduced 10-fold by thinning.

LITERATURE CITED

Barrett, James W.
1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv. Res. Pap. PNW-106, 16 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Hewlett, J. D., J. E. Douglass, and J. L. Clutter
1963. Instrumental and soil moisture variance using the neutron-scattering method. Soil Sci. 97(1): 19-24.

Hoover, M. W.
1971. Snow interception and redistribution in the forest. *In* Biological effects in the hydrological cycle, p. 114-122. Third Int. Semin. Hydrol. Professors Proc. (E. J. Monke, Ed.), UNESCO.

Sartz, R. S.
1972. Soil water depletion by a hardwood forest in southwestern Wisconsin. Soil Sci. Soc. Am. Proc. 36: 961-964.

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aS79.7 PNW-244

PNW-244

April 1975

SEEDING RECOMMENDATIONS FOR DISTURBED MOUNTAIN SLOPES IN NORTH CENTRAL WASHINGTON

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by

Glen O. Klock, *Principal Soil Scientist*

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ABSTRACT

Many native and introduced plant species were tested for their ability to become established on highly disturbed soils on upper elevation slopes in north central Washington. Latar orchardgrass, Drummond timothy, perennial ryegrass, Manchar smooth brome, and tall fescue proved to be the best adapted species. A starter fertilizer treatment is essential for successful plantings.

KEYWORDS: Soil management (forest), forest damage-) fire.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

A series of lightning fires in July and August 1970 resulted in major forest fires covering 138,000 acres (55 850 ha) on the Entiat and Chelan Districts of the Wenatchee National Forest and Twisp District of the Okanogan National Forest. During the fires, more than 135 miles (219 km) of major fireline up to 300 feet (90 m) in width were constructed with tractors. The majority of the firelines were placed on ridgetops ranging from 2,950 to 6,900 feet (900 to 2 100 m) elevation. Forest cover along the firelines ranged from ponderosa pine (*Pinus ponderosa* Laws.)[1/] at lower elevations to subalpine fir-whitebark pine (*Abies lasiocarpa* (Hook.) Nutt.-*Pinus albicaulis* Engelm.) at the upper elevations.

In most areas, major firelines were constructed with tractors during the fires. After the fires, tractors were used periodically through the summer of 1972 in a fuels management program to burn all construction residue. Surface condition after the tractor operation ranged from minimum disturbance, with little impact on the understory vegetation, to extreme disturbance where all vegetation was completely removed.

In the rehabilitation project after the fire, 926 acres (375 ha) of firelines were seeded and fertilized for erosion control.[2/] Seeding rates varied from 6 to 9 pounds per acre (6.7 to 10.1 kg/ha) of a mixture composed of orchardgrass (*Dactylis glomerata* L.), hard fescue (*Festuca ovina* var. *duriuscula* L.), timothy (*Phleum pratense* L.), and sweet clover (*Melilotus officinalis* (L.) Laws.). Fertilizer in the form of urea was applied at a rate of 70 pounds per acre (78 kg/ha). Both seed and fertilizer were broadcast by helicopter in late fall 1970. In many areas, particularly at higher elevations and on severely disturbed pumice soils, there was little evidence of seedling emergence and survival in September 1971.

STUDY

In 1971, a study was initiated to test the relative ability of the various plant species to become established under conditions present on these firelines; certified seed[3/] of 40 plant species were seeded on plots in the firelines. Fertilizer was applied as a secondary treatment. Four study locations, all on sites severely disturbed by tractor operation, were:

1. Dinkelman Ridge, elevation 4,100 feet (1 250 m). Soils are derived from Swauk sandstone parent material and are generally loamy sands. Local vegetation is mixed conifer, including Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and

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[1/] Scientific names of trees are according to Elbert L. Little, Jr., Checklist of native and naturalized trees of the United States (including Alaska). USDA Forest Service, Agriculture Handbook No. 41, 472 p., 1953.

[2/] R. F. Perkins, R. A. Woodward, and T. P. Ryan. Operational report of rehabilitation of the north central Washington fires. USDA Forest Service, Wenatchee National Forest Release, 33 p. 1971.

[3/] Most seed was provided by Mr. John L. Schwendiman, Plant Material Specialist, Soil Conservation Service, Pullman, Washington.

ponderosa pine with an understory of pinegrass (*Calamagrostis rubescens* Buckl.).[4/]

2. Sugarloaf Corral, elevation 5,050 feet (1 540 m). Soils are derived from Swauk sandstone. Local vegetation is predominantly lodgepole pine (*Pinus contorta* Dougl.), subalpine fir, and grouse whortleberry (*Vaccinium scoparium* Leiberg).

3. Handy Springs, elevation 6,560 feet (2 000 m). Soils are predominantly volcanic ash with some pumice. Vegetation is subalpine fir, whitebark pine, and various sedges (*Carex* spp.).

4. Silver Creek, elevation 4,500 feet (1 370 m). Soils are "popcorn" pumice with a thin layer of volcanic ash cover in some locations. Vegetation is lodgepole pine-grouse whortleberry.

Varieties and seeding rates used at each location are shown in table 1. An attempt was made to apply 100 seeds per square foot (328 seeds/m^2) for small seeds and 40 seeds per square foot (130 seeds/m^2) for large seed species. Fertilization was at the rate of 300 pounds per acre (336 kg/ha) of ammonium phosphate sulphate (16-20-0-15). Secondary plots without fertilization were also used for some varieties. Seed and fertilizer were applied by the broadcast method in late September 1971 on experimental plots 15- by 20-feet (4.6- by 6.1-m) in size. Legumes were not inoculated. Experimental plots were not replicated at each location.

Since a mixture of plant species was used in the 1970 postfire rehabilitation planting on the firelines, a test of competition among species appeared desirable, so we mixed several varieties of annuals and perennials on experimental plots. Composition and planting rate for each species used within several mixes are shown in table 2.

Ground coverage of the planted species was measured by the point method with 20 pins (see footnote 4) in August 1972 and again in August 1973.

RESULTS AND DISCUSSION

Table 1 presents a summary of seeding rates and percent plant cover for all experimental plots in 1972 and 1973. After 2 years of growth, four perennials appear to have been satisfactorily established at all planting locations. These were orchardgrass, timothy, perennial ryegrass,[5/] and smooth brome. These species germinated and became satisfactorily established (foliar cover greater than 20 percent of the soil surface) whether planted individually or in a mixture in the 2,950 to 6,890-foot (900- to 2 100-m) elevation zone. Tall fescue also showed an excellent foliar cover (38-to 68-percent) in the first year but appeared to freeze out in 1973 at high elevation Handy Springs.

[4/] Dorothy Brown. Methods of surveying and measuring vegetation. Commonwealth Bureau of Pastures and Field Crops, Bull. 42, 223 p. Farnham Royal, Bucks, England. 1954.

[5/] Scientific names not shown in text are listed in tables 1 and 2.

Table 1.--*Foliar cover on experimental plots for selected grasses, legumes, and shrubs, 1 and 2 years after planting*[1/]

Common name	Scientific name[2/]	Variety	Seeding rate	Oinkelman Ridge		Sugarloaf Corral		Handy Springs		Silver Creek	
				1972	1973	1972	1973	1972	1973	1972	1973
			kg/ha (lb/acre)	- - - - - - - - - - - - - - - *Percent* - - - - - - - - - - - - - - -							
Perennial grasses:											
Orchardgrass	*Dactylis glomerata*	Latar	10.8 (9.6)	50	42	70	72	37	32	30	40
Tall fescue	*Festuca arundinacea*	Alta	81.7 (72.9)	54	67	68	53	38	1	40	28
Hard fescue	*Festuca ovina* var. *duriuscula*	Durar	10.4 (9.3)	42	25	16	40	15	0	1	20
Sheep fescue	*Festuca ovina* var. *sulcata*		5.4 (4.8)	14	33	0	5	3	0	0	3
Smooth brome	*Bromus inermis*	Manchar	30.2 (26.9)	3/ 2(8)	40(3)	27(0)	33(10)	4/ 2(0)	0(0)	15(0)	23(0)
Beardless wheatgrass	*Agropyron inerme*	Whitmar	48.4 (43.2)	34	25	13	18	0	0	0	1
Intermediate wheatgrass	*Agropyron intermedium*	Amur	75.3 (67.2)	2	15	42	45	25	7	0	17
Intermediate wheatgrass	*Agropyron intermedium*	Greenar	58.4 (52.1)	52	42	57	28	18	0	28	17
Pubescent wheatgrass	*Agropyron trichophorum*	Topar	64.1 (57.2)	5	7	43	15	20	0	2	3
Siberian wheatgrass	*Agropyron sibiricum*		28.7 (25.6)	18	0	15	0	0	0	0	0
Slender wheatgrass	*Agropyron trachycaulum*	Primar	45.2 (40.3)	20	38	0	13	17	0	32	27
Streambank wheatgrass	*Agropyron riparium*	Sodar	40.9 (36.5)	0	0	2	2	0	0	0	30
Tall wheatgrass	*Agropyron elongatum*	Alkar	81.7 (72.9)	66	87	29	2	0	0	3	13
Thickspike wheatgrass	*Agropyron dasystachyum*		33.3 (29.7)	8	8	12	7	0	0	28	25
Big bluegrass	*Poa ampla*	Sherman	64.6 (57.6)	42	83	43	2	0	0	20	40
Canada bluegrass	*Poa compressa*		2.4 (2.1)	0	0	15	28	18	47	4	30
Indian ricegrass	*Oryzopsis hymenoides*		30.8 (27.5)	0	0	0	0	0	0	0	0
Perennial ryegrass	*Lolium perenne*		27.9 (24.9)	13	27	85	80	42	48	40	38
Timothy	*Phleum pratense*	Orummond	4.3 (3.8)	24	32	62	53	28	42	38	15
Blue wildrye	*Elymus glaucus*		41.9 (37.4)	0	0	0	0	0	0	0	0
Russian wildrye	*Elymus junceus*		43.1 (38.4)	0	0	0	0	0	0	0	0
Black medic	*Medico sativa*		27.6 (24.6)	0	0	--	--	--	--	--	--
Side oats grama	*Bouteloua curtipendula*		30.5 (27.2)	0	0	--	--	--	--	--	--
Lodorm green needlegrass	*Stipa viridula*		21.5 (19.2)	0	0	0	0	0	0	0	0
Common green needlegrass	*Stipa viridula*		33.0 (29.4)	0	0	--	--	--	--	--	--
Annual grasses:											
Common ryegrass	*Lolium* sp.		26.6 (23.7)	2(0)	0(0)	22(0)	30(1)	0(0)	0(0)	(4/)	--
Wheat	*Agropyron triticeum*		172.8 (154.1)	20(3)	0(0)	13(10)	0(0)	0(2)	0(0)	(4/)	--
Cereal rye	*Secale cereale*		109.8 (97.9)	32(5)	0(0)	30(10)	0(0)	17(5)	0(0)	(4/)	--
Legumes:											
Cicer milkvetch	*Astragalus cicer*	Cicar	46.3 (41.3)	0	0	0	0	0	0	0	0
Red clover	*Trifolium pratense*	Mammoth	25.8 (23.0)	0	0	0	0	2	0	0	0
Yellow sweet clover	*Melilotus officinalis*		29.0 (25.9)	0	0	1	0	0	0	0	0
Birdsfoot trefoil	*Lotus corniculatus*		12.6 (11.2)	0	0	0	0	0	0	0	0
Bramble vetch	*Vicia tenuifolia*		22.2 (19.8)	0	0	0	0	0	0	0	0
Common sainfoin	*Onobrychis viciaefolia*	Onar	98.6 (87.9)	3(0)	0(0)	3(1)	0(0)	5(9)	0(0)	(4/)	--
Shrubs:											
Antelope bitterbrush	*Purshia tridentata*		265.4 (236.7)	0	0	--	--	--	--	--	--

1/ All plots were fertilized with ammonium phosphate sulfate (16-20-0-15) at the rate of 336 kg/ha.

2/ Scientific names are according to Harlan P. Kelsey and William A. Oayton, Standardized plant names. 675 p. J. Horace McFarland Company, Harrisburg, Pa., 1942.

3/ Percent plant cover in another experimental plot of same plant variety but not fertilized is in parentheses.

4/ Experimental plot disturbed by tractor operation.

Table 2.--*Fertilized and unfertilized foliar cover on experimental plots for mixed plant species, 1 and 2 years after planting*

Common name	Scientific name[1/]	Variety	Seeding rate	Oinkelman Ridge				Sugarloaf Corral				Handy Springs			
				1972		1973		1972		1973		1972		1973	
				Fert.	No fert.	Fert.	No fert.	Fert.	No fert.	Fert.	No fert.	Fert.	No fert.	Fert.	No fert.
			kg/ha (lb/acre)	*Percent*											
Mix 1:															
Smooth brome	*Bromus inermis*	Manchar	11.2 (10.0)	8	0	10	0	0	0	5	0	0	0	0	8
Timothy	*Phleum pratense*	Orummond	1.1 (1.0)	23	3	28	13	8	0	42	0	7	5	45	30
Hard fescue	*Festuca ovina* var. *duriuscula*	Ourar	2.6 (2.3)	11	0	10	3	0	0	0	0	0	0	0	0
Crested wheat-grass	*Agropyron desertorum*	Nordan	7.3 (6.5)	0	0	8	0	0	0	0	0	0	0	0	2
	Total cover (above species)			42	3	56	16	8	0	47	0	7	5	45	40
Mix 2:															
Annual wheat	*Agropyron triticeum*		27.2 (24.3)	0	0	0	0	0	0	0	0	0	0	0	0
Common sainfoin	*Onobrychis viciaefolia*	Onar	19.7 (17.6)	3	0	0	0	0	0	0	0	0	0	0	0
Cereal rye	*Secale cereale*		4.4 (3.9)	7	8	0	0	0	0	0	0	15	0	0	0
Common ryegrass	*Lolium* sp.		4.7 (4.2)	0	0	0	0	0	0	5	0	3	0	0	0
Mustard	*Brassica* sp.	Giant	5.4 (4.8)	0	0	0	0	3	0	0	0	0	0	0	0
	Total cover (above species)			10	8	0	0	3	0	5	0	18	0	0	0
Mix 3:															
Annual wheat	*Agropyron triticeum*		23.0 (20.5)	8	3	0	0	2	0	0	0	2	0	0	0
Common sainfoin	*Onobrychis viciaefolia*	Onar	14.4 (12.8)	0	0	0	0	2	0	0	0	0	0	0	0
Cereal rye	*Secale cereale*		16.5 (14.7)	3	2	0	0	10	0	0	0	10	7	0	0
Smooth brome	*Bromus inermis*	Manchar	7.0 (6.2)	2	18	3	7	0	0	0	0	0	0	2	0
Timothy	*Phleum pratense*	Orummond	0.7 (0.6)	2	8	0	3	3	0	40	0	2	0	42	10
Hard fescue	*Festuca ovina* var. *duriuscula*	Ourar	1.5 (1.3)	2	0	0	3	2	0	2	0	0	0	0	0
Crested wheat-grass	*Agropyron desertorum*	Nordan	4.4 (3.9)	0	0	3	0	0	0	0	0	0	0	0	0
	Total cover (above species)			17	31	6	13	19	0	42	0	14	7	44	10
Mix 4:															
Mustard	*Brassica* sp.	Florida broadleaf	12.0 (10.7)	(2/)	--	0	0	3	0	0	0	3	0	0	0
Mustard	*Brassica* sp.	Giant curl	12.0 (10.7)	--	--	0	0	8	0	0	0	0	0	0	0
	Total cover (above species)			--	--	0	0	11	0	0	0	3	0	0	0
Mix 5:															
Garden pea	*Pisum sativum*	Austrian	223.0 (198.9)	3	7	0	0	7	0	7	0	12	8	0	0
Rape	*Brassica* sp.		32.3 (28.8)	8	7	0	0	5	0	0	0	10	2	0	0
	Total cover (above species)			11	14	0	0	12	0	7	0	22	10	0	0

[1/] Scientific names are according to Harlan P. Kelsey and William A. Oayton, Standardized plant names. 675 p. J. Horace McFarland Company, Harrisburg, Pa., 1942.

[2/] No species differentiation made.

The level of success with most species decreased with increasing elevation. Site preparation, need for fertilization, and correct time of planting must be more closely evaluated at higher elevations. Smooth brome did not establish satisfactorily at Handy Springs, primarily because the experimental site was disturbed by tractor operations after planting. We do not believe animal use had appreciable influence on success or failure of any particular species at any planting location.

Cereal rye was the only annual satisfactorily established on all fireline locations, but its primary value does not appear to be in the form of extensive live plant cover for the soil surface during the plant growth period. During the first growing season, it produces considerable dry matter which provides immediate protection for the soil surface. In subsequent years, this organic material may improve soil microclimate, particularly on harsh sites, resulting in a more acceptable site condition for the establishment of other plant species including natives such as sedges. The cereal rye experiment and plots of several other species were lost by disturbance from tractor operation at the Silver Creek location.

On the remaining plots, 11 species became established only within restricted elevations and soil types. Species and areas on which their use is not recommended are:

tall fescue	above 6,000-foot (1 830-m) elevation
hard fescue	above 6,000-foot (1 830-m) elevation
sheep fescue	above 5,000-foot (1 525-m) elevation and on coarse pumice soils
big bluegrass	above 6,000-foot (1 830-m) elevation
Canada bluegrass	below 4,500-foot (1 370-m) elevation
beardless wheatgrass	above 5,000-foot (1 525-m) elevation and on coarse pumice soils
intermediate wheatgrass (Amur)	on coarse pumice soils
intermediate wheatgrass (Greenar)	on coarse pumice soils
slender wheatgrass	above 4,500-foot (1 370-m) elevation
tall wheatgrass	above 5,500-foot (1 675-m) elevation and on coarse pumice soils
thickspike wheatgrass	above 4,500-foot (1 370-m) elevation

The inability of many species to become established at higher elevations appears to result from their susceptibility to damage from frost heaving, cold air and soil temperatures, short growing season, and high solar radiation levels. Although some of the tested plant species do not appear satisfactory for high elevations in north central Washington, they may be adaptable to similar elevations in other locations. Disturbed pumice soils found on the firelines are very coarse textured. Therefore, seed makes poor contact with the soil, resulting in poor nutrient and moisture availability and making establishment difficult for many plant species.

Many plant species appear unacceptable for general fireline use in the 2,950- to 6,900-foot (900- to 2 100-m) elevation zone of north central Washington. Species showing no evidence of emergence on the experimental plots were:

Indian ricegrass	green needlegrass
blue wildrye	Lodorm green needlegrass
Russian wildrye	black medic
Cicer milkvetch	side oats grama
birdsfoot trefoil	bitterbrush
bramble vetch	

Only a few plants emerged on the experimental plots seeded to sweet clover and red clover. Again we must point out that the legumes were not inoculated which could have had an important effect on their ability to become established.

Species showing establishment at one or more locations but which are not recommended for general use on firelines in north central Washington because of inadequate cover and vigor are:

pubescent wheatgrass	wheat
Siberian wheatgrass	mustard
streambank wheatgrass	pea
sainfoin	rape
common ryegrass	

Sainfoin appeared to be the only legume that might be successful on firelines. However, since legumes were not inoculated, this study probably does not provide a true indication of their suitability for seeding disturbed areas such as firelines. Because of their nitrogen-fixing capability, legumes are desirable in highly disturbed areas with low nitrogen capital. Also, their large seeds are excellent food for small animals and birds. It thus appears there should be more extensive research on the use of legumes, and in particular of sainfoin, for seeding areas as severely disturbed as firelines.

When several species were seeded as a mixture, growth of all species was less satisfactory than when seeded singly (table 2). With the exception of cereal rye, perennials predominantly provided the greatest ground cover in the mixed species plots. As in the individual species trials, fertilization substantially increased emergence, establishment, and ground cover. This can be attributed to the starter fertilizer effect reported by Klock.[6/] Two possible explanations for poor success of mixtures are reduced seeding rate of each individual species and competition. Quite possibly seeding rates of acceptable species were not high enough to compensate for lack of ground cover from nonacceptable plant species. Although we have no estimate of the importance of competition in this study, results can be compared with those of Tiedemann and Klock.[7/] In their study, of five species seeded after fire, only two, Latar orchardgrass and Durar hard fescue, provided enough ground cover to be considered successful. Cover of orchardgrass stabilized at 4 to 5 percent between the second and fourth years, and hard fescue cover increased during each of the

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[6/] G. O. Klock. Use of a starter fertilizer for vegetation establishment. (Abstr.) Northwest Sci. 43(1): 38. 1969.

[7/] Arthur R. Tiedemann and Glen O. Klock. Development of vegetation after fire, seeding, and fertilization on the Entiat Experimental Forest. Proceedings, 15th Tall Timbers Fire Ecology Conference., Oct. 16-17, 1974, Portland, Oreg.

4 years of their study. Perennial ryegrass and yellow sweet clover provided less than 0.1-percent cover during the first and second years and had disappeared completely from permanent transects by the third year. Drummond timothy cover declined after the second year.

Reasons for failures of the first nonexperimental fireline seedings are relatively unknown other than the periodic disruption of the seed bed by tractor operation for about 2 years. Orchardgrass and timothy are expected to establish when fertilized in most locations; however, the 6 pounds per acre (6.7 kg/ha) seeding rate would probably be marginal for this operation. Wind drift and air wash from the helicopter could have dispersed seed over a much greater area than was intended. Seeding rates equal to or above those in table 1 are recommended. The seed was applied quite late in the fall which may be too late for successful seed germination in the near alpine region. Subsequent fireline plantings of orchardgrass and timothy by the National Forest with a seed drill have been successful in areas below 6,000 feet (1 830 m). Above 6,000 feet, frost heaving was extreme in the spring of 1973; and many seedlings were lost.

CONCLUSIONS

Results of this study show that firelines with severely disturbed soil can be successfully revegetated by artificial seeding on the east Cascade upper slopes of north central Washington. Latar orchardgrass, Drummond timothy, perennial ryegrass, Manchar smooth brome, and tall fescue proved to be the best adapted species for this purpose. Limited success with mixtures of species, whether perennial or perennial-annual, indicates that the best ground cover will probably be achieved with one or two of the above selected species. A starter fertilizer treatment is imperative. Covering the seed by methods such as with a seed drill or harrowing and using mulches, particularly at higher elevations, can be expected to increase the level of success.

On severely disturbed soils, we highly encourage planting practices that will provide cover with native species. In many cases, native species do not spread quickly enough for needed soil surface protection or seed is not available in large quantities. Therefore, a need does exist for the use of "introduced" species.

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GPO 993-416

ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

2 77 PNW 245

PNW-245 April 1975

EVALUATIONS ON ACCELERATING WOOD DECOMPOSITION IN THE FIELD

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by

Franklin R. Ward, *Forest Technician*

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ABSTRACT

Treatment of pieces of Douglas-fir with nitrogenous chemicals, a mixture of 2,4-D and 2,4,5-T, or a plastic spray failed to accelerate decay of wood specimens in the field. Therefore, adding these various chemicals is not recommended treatment for residue reduction.

Keywords: Slash disposal, decay fungi (wood)

INTRODUCTION AND OBJECTIVE

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) logging residue may impede regeneration and cause fire hazard problems in Pacific Northwest forests. Since decay of Douglas-fir is relatively slow, these problems can persist for many years (Childs 1939, Wagener and Offord 1972). The land manager neither long postpones regeneration nor tolerates fire hazards on harvested lands. Acceleration of decay offers one way to reduce residues.

The objective of this study was to see if decomposition could be accelerated by treating Douglas-fir wood with varying amounts of ammonium phosphate, urea (45-percent), asparagin, a mixture of equal amounts of 2,4-D and 2,4,5-T, or a plastic spray for moisture retention.

Wood decay is caused by enzymes secreted by saprophytic fungal mycelium (Boyce 1961). The fungus penetrates between and into cells and is capable of breaking down the wood and using it for food (U.S. Forest Products Laboratory 1974). Wood is composed mainly of cellulose and hemicellulose, which account for 60 to 70 percent of the cell wall, and lignin which accounts for 15 to 35 percent (Panshin and DeZeeuw 1964).

Nitrogen usually comprises less than 0.1 percent of the dry weight of wood (Merrill and Cowling 1966). Kaufert and Behr (1942) report that wood treated with urea is more susceptible to decay than untreated wood. Others (Cartwright and Findlay 1950, Curtis 1957, Schmitz and Kaufert 1936, Zycha 1940) have shown in laboratory tests that adding nitrogenous substances increases the rate of decay.

Pruning with chemicals 2,4-D and 2,4,5-T accelerates natural pruning by deadening the branches of hardwoods (MacConnell and Kenerson 1964). Personnel of the Fuel-Break Project[1/] observed that shrubs killed with 2,4-D decay more rapidly than fire-killed shrubs.

Curtis (1957) reports that a solution of 2,4-D and 2,4,5-T in diesel oil with fertilizer applications has been used to help accelerate decay of stumps. No work has been done to see if decomposition of wood is increased by treatment with a solution of only 2,4-D and 2,4,5-T.

STUDY PROCEDURE

Field

Study plots were established on a test area located on the Estacada Ranger District, Mount Hood National Forest, Oregon. The area was in a Douglas-fir and western hemlock stand (*Tsuga heterophylla* (Raf.) Sarg.) with no underbrush on a north-facing slope.

Each plot was a circular milacre. Ten plots, one for each of nine treatments, plus one control were located in a line with at least 3 feet (0.914 m) but not more than 6 feet (1.8 m) between plots. This configuration of 10 plots was replicated four times. The four 10-plot series were laid out in a random compass array extending from a point near the center of the experimental site.

1/ Headquartered at the Forest Fire Laboratory, U.S. Forest Service, Riverside, California.

No 10-plot series was closer than 10 feet (3.048 m) to another. Sapwood samples, 2 inches x 2 inches x 4 inches (5.08 cm x 5.08 cm x 10.16 cm), were cut from a felled Douglas-fir bole and installed in the plots in September. Six wood samples were placed in each plot within a week after cut and treated immediately after. Each sample was placed horizontally directly beneath the duff and litter layer in contact with the soil surface. Treatments were randomized within each 10-plot series and exposed to one of the 10 treatments. A quart (0.9463 l) of water was used as the carrying agent for the nitrogenous compounds and sprinkled directly on the samples of wood. A quart of water was applied to each control plot.

The chemicals used and amounts of each application are listed below.

Seven untreated pieces of wood were stored in a room with uncontrolled temperature and humidity for future comparison with the treated blocks.

Blowdown destroyed 8 of 40 plots, so samples were collected from only 32 plots. The samples were retrieved from the field after being exposed for 33 months, placed in plastic bags, and shipped to University of Washington for analysis.

Treatment	Chemical compound	Amount	Per acre equivalent
1	Ammonium phosphate	0.25 lb (0.113 kg)	40 lb N (44.83 kg/ha)
2	Ammonium phosphate	0.75 lb (0.34 kg)	120 lb N (134.50 kg/ha)
3	Urea	0.089 lb (0.04 kg)	40 lb N (44.83 kg/ha)
4	Urea	0.267 lb (0.121 kg)	120 lb N (134.50 kg/ha)
5	Asparagin	0.167 lb (0.076 kg)	40 lb N (44.83 kg/ha)
6	Asparagin	0.5 lb (0.227 kg)	120 lb N (134.50 kg/ha)
7	2,4-D and 2,4,5-T	0.0015 gal (0.00568 l)	3 lb each herbicide (3.363 kg/ha)
8	2,4-D and 2,4,5-T	0.003 gal (0.011 l)	6 lb each herbicide (6.725 kg/ha)
9	Plastic spray (moisture retention)	7 oz (198.447 g)	--
10	Water (control)	1 qt (1.946 l)	--

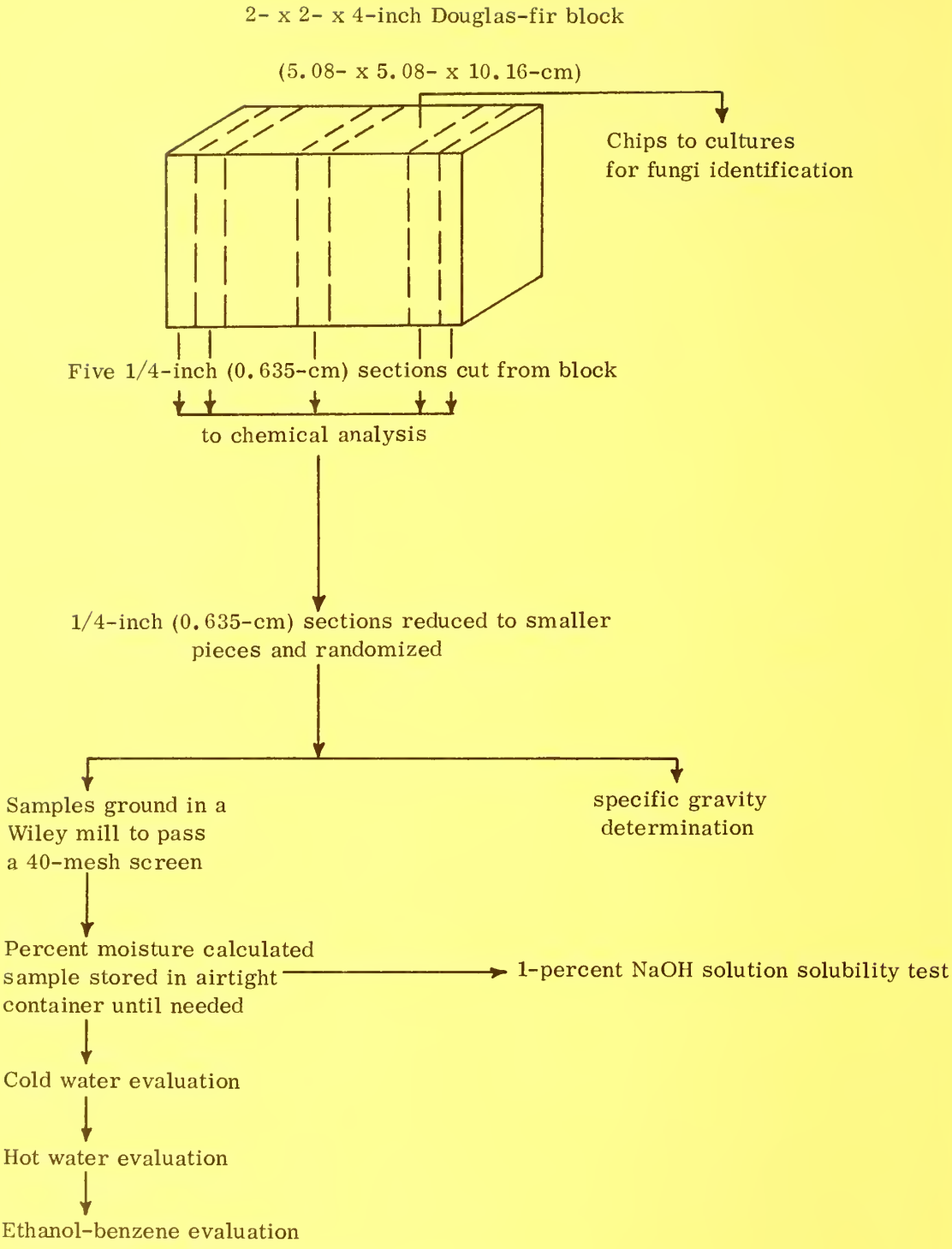

Figure 1.--*Flow chart for solubility and specific gravity tests.*

Laboratory

Samples were prepared for analysis by cutting five 1/4-inch (0.635-cm) sections from each piece of wood. One section was taken from the middle and two from each end of the wood samples (fig. 1). The five sections were dried at 60°C (140°F) for 72 hours to stop decomposition and to prepare the pieces for grinding. After drying, each section was cut into smaller pieces and all pieces from the five sections were mixed together. About 0.21 ounce (6 g) were removed for determining specific gravity. The remainder was ground in a Wiley mill[2/] to pass a 40-mesh screen and then placed in an airtight container. Samples were removed from the container as needed for analysis and solubility.

As wood decays, depolymerized and modified fragments of wood extractives, hemicellulose, cellulose, and lignin become more soluble in neutral solvents and sodium hydroxide (NaOH) (fig. 2).

[2/] Mention of product by name does not imply endorsement by the U.S. Department of Agriculture.

Figure 2.--Effect of decay on increasing solubility of wood components.

	SOUND WOOD COMPONENTS	DECAYED WOOD COMPONENTS
SOLUBLE IN:		
Neutral solvents*	Extractives	Extractives Hemicellulose Cellulose
1-percent NaOH	Extractives Hemicellulose	Extractives Hemicellulose Cellulose
INSOLUBLE IN:		
Neutral solvents*	Hemicellulose Cellulose Lignin	Lignin≠
1-percent NaOH	Cellulose Lignin	Lignin≠

*Cold water, hot water, and ethanol benzene.
≠Soluble in trace amounts only.

Therefore, TAPPI solubility and specific gravity tests (Technical Association of the Pulp and Paper Industry 1974) were made to determine the extent of decay in each block. The standard TAPPI tests, listed with each solubility stage, are:

Solubility test	TAPPI procedures
Moisture percent	T11M - 59
Cold water	T1M - 59
Hot water	T1M - 59
Ethanol-benzene	T6M - 50
1-percent NaOH	T4M - 59
Specific gravity	18M - 53

The sequence of analysis is outlined in figure 1. Two of each TAPPI test for each evaluation were made for each block.

Samples were taken from the pieces of wood for culture of decay organisms. A sterile razor blade was used to expose a fresh area on each block sampled. Small chips of wood were removed from each exposed area with sterile microforceps. Each chip was placed on Martin's dextrose-peptone media fortified with 0.00123 ounce (0.035 g) of rose bengal and 30.0 micrograms per milliliter (0.0005 oz per pt) of streptomycin sulfate and incubated (temperature 24°C-28°C, or 75.2°F-82.4°F). Fungi that did not sporulate or those not readily recognizable were transferred to plates of 2-percent malt agar media and incubated until they could be identified.

An analysis of variance was performed comparing solubility and specific gravity tests to determine any significant difference in decay among the treated blocks and control test blocks in the test area. The 95-percent probability level was used for judging significance.

RESULTS

All blocks of wood appeared solid with little or no evidence of decay. However, the laboratory tests revealed some decomposition had taken place. Although there was variability among blocks of wood, the total solubility was about 32 percent for treated and control specimens. Neutral solvents accounted for 8.7 percent and 1-percent NaOH, 23.26 percent (table 1).

Table 1.--*Solubility of test pieces, based on moisture-free weight*

Mean	Solubility in				
	Cold water	Hot water	Ethanol benzene	1-percent NaOH	Total
	Percent				
Mean of all treatments	4.57	2.67	1.46	23.26	31.96

The pieces of wood stored in the room showed a mean total solubility of 18.76 ± 6.91 at the 95-percent confidence level. The results showed there was a difference between samples collected from the field and those stored in the room. However, an analysis of variance indicated there was no evidence of any significant difference (at the 95-percent confidence level) among the various treatments for pieces collected from the field.

The values of the two laboratory tests for each treatment varied less than 1 percent, so each mean was used for the analysis of variance computations.

The micro-organisms isolated from wood chips were:

Isolate	Frequency (percent)
Penicillium spp.	28
Trichoderma spp.	21
Sterile mycelium	16
Bacteria	6
Basidiomycete	6
Sporotrichum spp.	6
Red mucor spp.	4
Sporothrix spp.	4
Cylindrocladium spp.	3
Trichosporon spp.	3
Acromoniella spp.	1
Cephalosporium spp.	1
Rhizopus spp.	1

Of the 67 percent of the micro-organisms isolated above in the class Imperfect Fungi, species of *Penicillium* and *Trichoderma* accounted for 73 percent. Sterile mycelium (16 percent) were those fungi that did not sporulate and did not show the presence of clamp connections. The Basidiomycetes were identified on the basis of clamp connections exhibited on the vegetative hyphae.

CONCLUSIONS

As expected, the stored, untreated, air-dry samples exhibited the lowest solubilities. The treated and control pieces of wood showed an increased solubility of about 13 percent, indicating decomposition was taking place. However, decomposition was not significantly influenced by the various chemical treatments as shown by the analysis of variance. Therefore, addition of the nitrogenous materials tested, a solution of 2,4-D and 2,4,5-T, or a plastic compound is not recommended treatment for residue reduction.

ACKNOWLEDGMENT

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LITERATURE CITED

Boyce, John Shaw
1961. Forest pathology. 572 p. McGraw-Hill Book Co., Inc., New York.

Cartwright, K. St. G., and W. P. K. Findlay
1950. Decay of timber and its prevention. 294 p. Chemical Publ. Co., Inc., Brooklyn, N. Y.

Childs, Thomas W.
1939. Decay of slash on clearcut areas in the Douglas-fir region. J. For. 37(12): 955-959.

Curtis, O. F.
1957. Influence of herbicides and fertilizers on stump decay. Weed Abstr. 6(7): 293-299.

Kaufert, F. H., and E. A. Behr
1942. Susceptibility of wood to decay: effect of urea and other nitrogen compounds. Ind. & Eng. Chem. 34: 1510-1515.

MacConnell, William P., and Laurey Kenerson
1964. Chemi-pruning northern hardwoods. J. For. 62(7): 463-465.

Merrill, William, and Ellis B. Cowling
1966. Role of nitrogen in wood deterioration: amounts and distribution of nitrogen in tree stems. Can. J. Bot. 44: 1555-1580.

Panshin, A. J., and Carl DeZeeuw
1964. Textbook of wood technology. Vol. 1. Structure, identification, uses, and properties of the commercial woods of the United States. 643 p., illus. McGraw-Hill Book Co., Inc., New York.

Schmitz, H., and F. H. Kaufert
1936. Effect of certain nitrogenous compounds on the rate of decay of wood. Am. J. Bot. 23: 635-638.

Technical Association of the Pulp and Paper Industry
1974. TAPPI standards or suggested methods. Tech. Assoc. Pulp & Pap. Ind., New York.

U.S. Forest Products Laboratory
1974. Wood handbook: wood as an engineering material. U.S. Dep. Agric. Agric. Handb. 72, rev., 421 p., illus. Madison, Wis.

Wagener, Willis W., and Harold R. Offord
1972. Logging slash: its breakdown and decay at two forests in northern California. USDA For. Serv. Res. Pap. PSW-83, 11 p., illus. Pac. Southwest For. & Range Exp. Stn., Berkeley, Calif.

Zycha, H.
1940. The influence of nutrient salts on the decomposition of wood by fungi. Holz 3: 50-51.

GPO 993-415

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

113.79: PNW-246

April 1975

DISTRIBUTION OF AERIALLY APPLIED *BACILLUS THURINGIENSIS* FOR CONTROLLING DEFOLIATING INSECTS IN A HARDWOOD FOREST

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Bohdan Maksymiuk, *Principal Entomologist*

and

R. D. Orchard, *Biological Laboratory Technician*

Abstract

*Both Dipel® and Thuricide® (*Bacillus thuringiensis *Berliner) water-base spray formulations were aerially applied at a rate of 2 gal/acre to the semiclosed canopy of an oak forest in New York State to develop improved methods for controlling the gypsy moth.*

Techniques have been developed for quantifying spray deposit directly on hardwood foliage. No statistical differences were apparent between Dipel and Thuricide in mean drop-size spectra, deposit coverage of the forest canopy, and deposit distribution at the forest floor. The average volume median diameter of Dipel formulation recovered along subplot transects was 335 μm; that of Thuricide, 351 μm. On the average, about 10 percent of the spray deposit was recovered from the upper oak crowns, 8 percent from the lower crowns, 9 percent from under the sample trees at forest floor level, and 9 percent along the subplot transect lines at the forest floor level. The mean number of drops per square centimeter of foliage was six on the upper oak crowns, four on lower crowns, five under the trees, and five on Kromekote® cards along the deposit sampling lines. A higher deposition of spray in the forest canopy is needed for increased effectiveness of insect control.

KEYWORDS: *Insect damage control (hardwood forest), defoliation damage, spraying (-pest control.*

INTRODUCTION

Environmentally acceptable *Bacillus thuringiensis* Berliner (*B.t.*) offers a potential for controlling forest defoliating insect pests (Tripp 1972, Smirnoff et al. 1973, Lewis et al. 1974, Maksymiuk and Orchard 1974). Success or failure of aerial application of insecticides, such as *B.t.*, and insect viruses depends on adequate and uniform coverage of tree crowns with spray deposit.

Quantitative information on distribution of spray deposit for the oil-based chemical insecticide (Zectran[1/]) has been recently developed.[2/] Lewis and Connola (1966) emphasized the need for similar information to better evaluate use of *B.t.* to control the gypsy moth (*Porthetria dispar* (Linnaeus)).

A study was conducted to obtain information on spray deposit distribution as part of the field experiment to control the gypsy moth with Dipel® and Thuricide® *B.t.* water-base spray formulations in the State of New York in 1972 (Lewis et al. 1974).

This paper describes developed techniques and presents results on the drop-size spectra and the quantitative vertical and horizontal spray deposit distribution of Dipel and Thuricide in the hardwood forest canopy and at the forest floor level.

MATERIALS AND METHODS

Test Area

The experimental plots were located in the mountainous terrain on ridgetops south of Howes Cave, New York. Predominant tree species were chestnut oak (*Quercus prinus* L.), white oak (*Q. alba* L.), and northern red oak (*Q. borealis* Michx. f.). These trees, from 5 to 8 inches (in) in diameter, comprised a semiclosed forest canopy.

[1/] *Mention of products and companies by name does not constitute endorsement by the U.S. Department of Agriculture, nor does it imply approval of a product to the exclusion of others which may also be suitable.*

[2/] *Bohdan Maksymiuk, John Neisess, R. A. Waite, and R. D. Orchard. Distribution of aerially applied mexacarbate in a coniferous forest and relationship to mortality of western spruce budworm. Unpublished data on file at Forestry Sciences Laboratory, Corvallis, Oregon, 1974.*

Formulations

Two preparations of *B.t.* were used. Dipel formulation contained: Dipel, a wettable powder (Abbott Laboratories, North Chicago, Ill.)--1 pound (lb); Cargill's Insecticide Base (Cargill, Inc., Minneapolis, Minn.)--2 quarts (qt); Chevron Spray Sticker (Chevron Chemical Co., San Francisco, Calif.)--6 fluid ounces (oz); and water--to make 2 gallons (gal). Thuricide (an emulsifiable concentrate) formulation contained: Thuricide-HPC (Sandoz, Inc., Homestead, Fla.)--2 qt; Cargill's Insecticide Base--2 qt; Chevron Spray Sticker--6 fl oz; water--to make 2 gal. In each of two spray applications, 2 gallons per acre of each formulation, containing *B.t.* equivalent to about 8 billion International Units of potency, were used.

Fluorescent tracers that absorb and fluoresce at different wavelengths were added to the spray formulations for quantitative assessment of spray deposit. Brilliant Sulphoflavine FFA was used for the first application, and Rhodamine B. Extra S (both from General Aniline and Film Corp., New York, N.Y.) was used for the second application (0.1-percent-weight-per-volume concentration).

Aerial Application

The physical layout was identical for both Dipel and Thuricide treatments. Two 80- to 100-acre plots were treated twice with Dipel and two with Thuricide. Each of the four test plots contained five 0.1-acre subplots (fig. 1). The first spray application was made when oak leaves were about half-grown. The second application was about 10 days later. The insecticide treatments for this study were assumed to be a completely random assignment to the four plots. Sides of the trees and applications were handled as split plot factors of the chemical whole plot treatments. The relationship between top and sides was analyzed for each plot using subplots as replications.

Estimated windspeed during applications ranged from 1 to 10 miles per hour (mi/h). Spray was applied by a fixed-wing aircraft (Grumman AgCat) equipped with four Beecomist® spinning nozzles (Beeco Products Co., Fort Washington, Pa.). The spray system was calibrated to deliver 2 gal per acre (18.71 liters/hectare) for 100-foot (30.48-meter) swath width. Spraying speed was about 85 mi/h (38 m/sec) and spraying height was about 45 ft (13.71 m) above forest canopy. Separate spray deposit assessments were made on the four plots after each of the two applications.

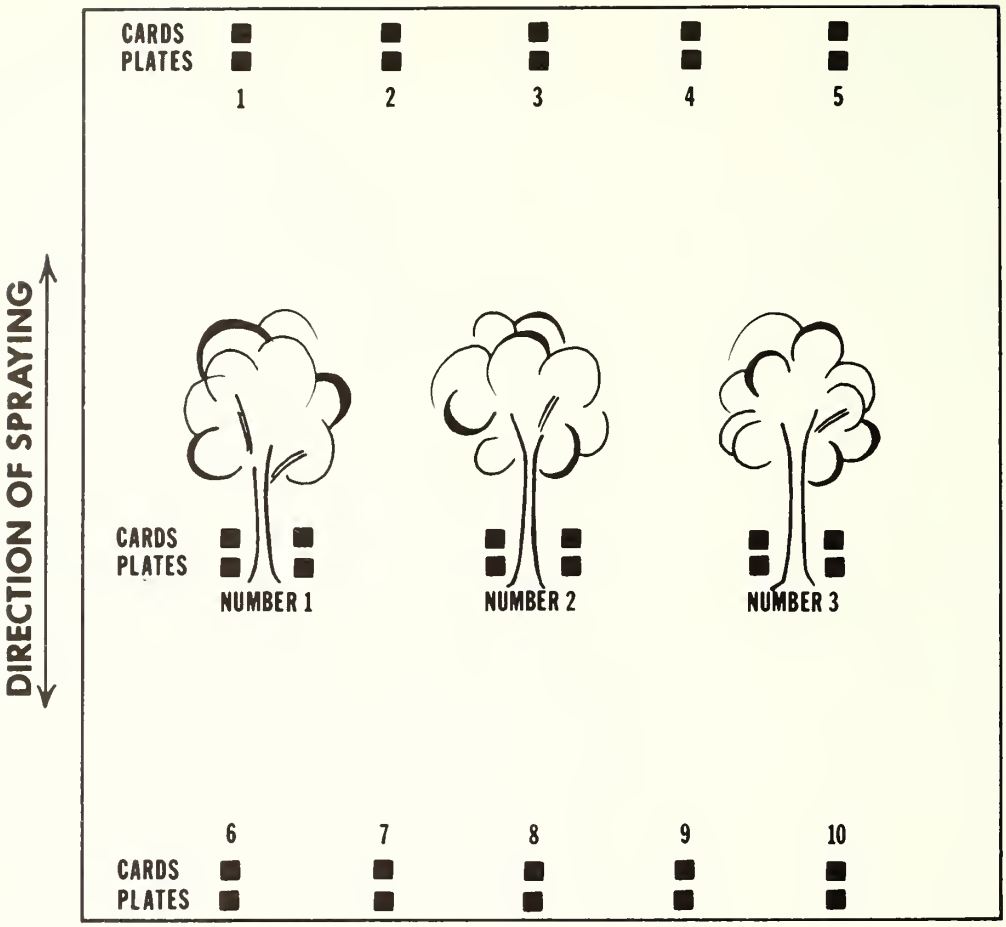

Figure 1.--Subplot layout showing sampling trees for determining spray deposit coverage of the tree crowns, and pairs of Kromekote cards with aluminum plates for assessing spray deposit at the forest floor level.

Drop-Size Spectra

The volume median diameter[3/] was determined by methods developed by Maksymiuk and Moore (1962) and Maksymiuk (1964). Kromekote® cards, supported by wire cardholders (Maksymiuk 1959), were placed along sampling lines and under sampling trees to sample deposit for determining vmd (fig. 1)

[3/] *Volume median diameter (vmd) is the diameter of a drop which satisfies the requirement that half the volume of liquid be in drops smaller than itself and half in drops larger.*

Spray Deposit Coverage of Tree Crowns

Each subplot contained three oak trees for sampling deposit on tree crowns. Oak foliage samples were used for determining spray deposit in gallons per acre and number of spray drops per square centimeter. Immediately after the spraying, foliage samples were collected from the upper (top) and lower crowns from the four sides (north, south, west, and east) of each of the three sample trees in each subplot. About 25 leaves were taken from each crown level. This foliage was carefully examined to exclude any insects. Then the samples were placed in paper bags which were sealed and labeled. All samples were shipped to the Forestry Sciences Laboratory in Corvallis, Oregon, for spray deposit analysis.

For determining the deposit on foliage in gallons per acre, 51 disks, 1 centimeter (cm) in diameter, were cut out of each crown sample of randomly selected leaves. Before the disks were cut, foliage samples were placed overnight in the refrigerator to absorb moisture, thereby reducing brittleness. The disks were cut from different locations on the individual leaves to account for the variability of deposit distribution. The samples, representing 40 cm^2 of the foliage area, were used for spray deposit assessment.

The deposit was eluted with distilled water from the 40 cm^2 of foliage disks. The amount of fluorescent tracer in the wash was determined by Turner spectrofluorometer, Model 430. The quantity of tracer for each sample was obtained from a previously developed standard curve showing the linear relationship between the amount of fluorescent tracer and fluorometer reading. Data were adjusted for the natural fluorescent background of the foliage samples, obtained shortly before the application of *B.t.* and for percent recovery of the fluorescent material from oak foliage, then converted to gallons per acre. This technique was similar to that described by Maksymiuk et al. (see footnote 2) for quantifying deposit on coniferous foliage, adapting the general principles reported by Yates and Akesson (1963).

Similarly, for determining number of spray drops, 51 disks, 1 cm in diameter, representing 40 cm^2 of leaf, were used. The spray drops containing fluorescent tracer were counted under a microscope illuminated by reflected ultraviolet light.

Spray Deposit Distribution at the Forest Floor

Aluminum plates (6 by 6 in) and white Kromekote cards (4 by 5 in) were positioned under the sample tree canopies and along the subplot transect lines at right angles to the direction of the spraying aircraft.

Two aluminum plates and two Kromekote cards were positioned under the canopy of each sample tree. The quantity in gallons per acre of the spray

deposit recovered on aluminum plates at ground level under the tree canopies was determined by fluorometric analysis. The deposit on the plates was eluted with distilled water, read in a spectrophotometer, compared with a previously developed reference curve, and then corrected for percent recovery of the fluorescent material.

The number of drops was determined from the Kromekote cards by counting the drops in a 4-cm^2 central area of each Kromekote card, under a dissecting microscope illuminated by ultraviolet light.

RESULTS AND DISCUSSION

Drop-Size Spectra

Data are summarized in table 1. Based on analysis of variance, no statistically significant differences were detected among any of the mean vmd's compared. The variation in the drop-size spectra can be attributed to the differential screening effect by foliage on deposit (Maksymiuk 1963a), the variation in performance of the Beecomist spinning nozzles, and the presence of plant fibers in the spray formulation traceable to the molasses used in the Cargill Insecticide Base.

Spray Deposit Coverage of Tree Crowns

Dipel and Thuricide spray deposits on oak trees are shown in tables 2 and 3. The mean deposit, both in gallons per acre and number of drops per square centimeter, was higher for Thuricide than for Dipel treatments. However, this difference was not large enough to be detected as significant ($P<0.05$) when tested by analysis of variance.

The horizontal spray deposit distribution on the four sides of the lower portions of the tree crowns is given in table 2. No statistically significant differences were detected between the mean Dipel and Thuricide deposits for the first, second, and combined applications.

The deposits for Dipel and Thuricide were combined to obtain a larger sample size for testing reproducibility of spray applications. The mean Dipel and Thuricide spray deposit for the first spray application (0.202 gal/acre) was higher than the mean deposit for the second application (0.103 gal/acre). This mean difference was highly significant ($P<0.009$). It can indicate the need to increase the accuracy of aerial application for more reproducible field treatments. No statistical differences were detected in the mean deposit expressed in the number of drops per square centimeter.

Vertical spray deposit distribution is presented in table 3. Amounts of spray deposited on the upper and the lower portions of the tree crowns are compared. Consistently, more spray was deposited on the upper than

Table 1.--*Drop-size spectra of* Bacillus thuringiensis *formulations*

Plot	Dipel			Plot	Thuricide		
	Application number	Along transects	Under trees		Application number	Along transects	Under trees
		Volume median diameter, μm					
A	1	[1/] 296±119	--	C	1	414±114	--
A	2	374±161	--	C	2	249±47	--
B	1	376±117	437±233	D	1	395±64	279±92
B	2	294±222	283±286	D	2	346±104	316±128
Mean		335±59	360±150	Mean		351±44	298±66

[1/] Confidence intervals are given at the 95-percent probability level.

Table 2.--*Comparison of mean spray deposit on the sides of the tree crowns*

Crown side	Application number	Dipel[1/]		Thuricide[2/]		Dipel + Thuricide	
		Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter
North	1	0.186	1.6	0.249	6.5	0.218	4.0
	2	.057	2.3	.141	3.4	.099	2.8
	1+2	.122	2.0	.195	5.0	.158	3.4
South	1	.219	1.5	.174	7.0	.196	4.2
	2	.083	2.8	.115	3.6	.099	3.2
	1+2	.151	2.2	.144	5.3	.148	3.7
East	1	.153	1.5	.201	6.2	.177	3.8
	2	.075	2.4	.136	3.7	.106	3.0
	1+2	.114	2.0	.168	5.0	.141	3.4
West	1	.193	1.7	.241	6.0	.217	3.8
	2	.070	2.6	.144	3.7	.107	3.2
	1+2	.132	2.2	.192	4.8	.162	3.5
Mean of four sides	1	.188	1.6	.216	6.4	.202	4.0
	2	.071	2.5	.134	3.6	.103	3.0
	1+2	.130	2.0	.175	5.0	--	--

[1/] Plot A + B.
[2/] Plot C + D.

Table 3.--*Comparison of mean spray deposit on the tops and sides of tree crowns*

Tree crown	Application number	Dipel[1/]		Thuricide[2/]		Dipel + Thuricide	
		Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter
Top	1	0.204	1.5	0.209	14.7	0.206	8.1
Sides		.169	1.0	.151	11.1	.160	6.0
Top	2	.112	1.9	.286	6.4	.199	4.2
Sides		.071	1.2	.169	3.9	.120	2.6
Top	1+2	.158	1.7	.252	10.6	.205	5.9
Sides		.120	1.1	.158	7.5	.139	4.0
Top + sides[3/]	1	.186	1.2	.180	12.9	.183	7.0
Top + sides	2	.091	1.6	.228	5.2	.160	3.3
Top + sides	1+2	.139	1.4	.204	9.0	--	--

[1/] Plot B.

[2/] Plot D.

[3/] Statistical tests were not made for marginal means because plots were not replicated for assessing deposit on treetops.

the lower portions of the tree crowns. However, because of deposit variation among subplots, the differences between crown levels were not statistically significant for the Dipel and Thuricide treatments for the first, second, and combined applications except for the second application of the Thuricide treatment. In this case, the mean spray deposit for the combined applications (0.252 gal/acre) on the upper tree crowns was significantly higher compared with the mean deposit (0.158 gal/acre) on the lower crowns ($P<0.044$). Interaction between insecticides and crown sides was not significant, either for deposit in gallons per acre or for number of drops per square centimeter.

Spray Deposit Distribution at the Forest Floor

Spray deposits recovered under sampling trees and along sampling transects for both applications of Dipel and Thuricide are presented in table 4. Because of a lack of replication, no statistical analysis of the data was made, except for spray deposit along transects expressed in drops per square centimeter. Based on the analysis of variance, no statistical differences were detected between the mean spray deposits of Dipel and Thuricide, between applications, and interaction between insecticides and applications for the deposit under the sampling trees and along the transects (table 4).

Table 4.--*Comparison of spray deposit distribution of* Bacillus thuringiensis *at forest floor level*

Plot	Dipel					Plot	Thuricide				
	Application number	Under trees		Along transects			Application number	Under trees		Along transects	
		Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter			Gallons per acre	Drops per square centimeter	Gallons per acre	Drops per square centimeter
A	1	--	--	--	3.3±1.4	C	1	--	--	--	6.0±3.2
A	2	--	--	--	4.1±0.6	C	2	--	--	--	4.6±2.0
B	1	[1/]0.117±.063	3.8±1.1	0.137±.088	4.1±1.3	D	1	0.189±.130	10.8±5.1	0.215±.147	10.8±4.8
B	2	.199±.412	1.8±1.0	.196±.232	1.6±0.9	D	2	.236±.169	4.0±2.2	.198±.110	5.0±1.9
Mean		.158±.207	2.8±0.6	.167±.133	3.3±0.3	Mean		.212±.125	7.4±3.4	.206±.113	6.6±0.6

[1/] Confidence intervals are given at the 95-percent probability level.

If we assume a uniform application rate of 2.0 gal/acre, only 7.9 percent of the Dipel spray was recovered under sampling trees and only 8.4 percent along subplot deposit sampling lines. For Thuricide, 10.6 percent of deposit was recovered under the sampling trees, and 10.3 percent along subplot transects.

The direct method of sampling spray deposit on foliage for correlating it with insect mortality (Maksymiuk et al., see footnote 2) has an advantage compared with the indirect methods of sampling spray deposit reaching ground level (Maksymiuk 1963b). The impingement of spray drops can be affected by the physical, morphological, and biological characteristics of the particular sampling surface, associated airmass movements, and electrostatic charges. Therefore, the spray deposit should be sampled directly on the foliage where insects are feeding for determining dose-response relationships.

In conclusion, our techniques for sampling and quantifying spray deposit were satisfactory. Improved aerial application methodology is needed for obtaining more uniform and higher deposit coverage of the forest canopy. This can be achieved by combining more-suitable spray formulations and atomizing devices for desirable drop-size spectra and by increasing the accuracy of aerial applications.

METRIC CONVERSIONS

1 inch = 2.54 centimeters
1 gallon = 3.785 liters
1 fluid ounce = 29.57 milliliters
1 pound = 453.59 grams
1 quart = 0.9463 liters
1 foot = 0.3048 meters
1 gallon per acre = 9.354 liters/hectare
1 mile per hour = 44.704 centimeters per second

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LITERATURE CITED

Lewis, F. B., N. R. Dubois, D. Grimble, W. Metterhouse, and J. Quimby
1974. Gypsy moth: efficacy of aerially applied *Bacillus thuringiensis*. J. Econ. Entomol. 67: 351-354.

Lewis, Franklin B., and Donald P. Connola
1966. Field and laboratory investigations of *Bacillus thuringiensis* as a control agent for the gypsy moth, *Porthetria dispar* (L.). USDA For. Serv. Res. Pap. NE-50, 38 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Maksymiuk, Bohdan
1959. Improved holders for spray deposit assessment cards. J. Econ. Entomol. 52: 1029-1030.

Maksymiuk, Bohdan
1963a. Screening effect of the nearest tree on aerial spray deposits recovered at ground level. J. For. 61: 143-144.

Maksymiuk, Bohdan
1963b. Spray deposit on oil-sensitive cards and spruce budworm mortality. J. Econ. Entomol. 56: 465-467.

Maksymiuk, Bohdan
1964. The drop size spectra method for estimating mass median diameter of aerial spray. USDA For. Serv. Res. Pap. WO-1, 9 p. Washington, D.C.

Maksymiuk, Bohdan, and A. D. Moore
1962. Spread factor variation for oil-base, aerial spray. J. Econ. Entomol. 55: 695-699.

Maksymiuk, Bohdan, and R. D. Orchard
1974. Techniques for evaluating *Bacillus thuringiensis* and spray equipment for aerial application against forest defoliating insects. USDA For. Serv. Res. Pap. PNW-183, 13 p. Portland, Oreg.

Smirnoff, W. A., J. J. Fettes, and R. Desoulniers
1973. Aerial spraying of a *Bacillus thuringiensis*-chitinase formulation for control of the spruce budworm (Lepidoptera: Tortricidae). Can. Entomol. 105: 1535-1544.

Tripp, H. A.
1972. Field trials to control spruce budworm, *Choristoneura fumiferana* (Clem.), through aerial application of *Bacillus thuringiensis*. Entomol. Soc. Ont. Proc. 103: 64-69.

Yates, W. E., and N. B. Akesson
1963. Fluorescent tracers for quantitative microresidue analysis. Trans. Am. Soc. Eng. 6: 104-107, 114.

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RESPONSE OF POLE-SIZE LODGEPOLE PINE TO FERTILIZATION

by

P. H. Cochran, *Research Soil Scientist*

ABSTRACT

Large, significant increases in annual volume, basal area, and bole area growth, as well as grass production in the understory, were obtained during a 4-year period after application of N, P, and S. Measurements of annual radial wood growth indicate that these favorable responses will last longer than 4 years. Height growth and soil water use were not increased significantly by fertilization, but sampling error may have masked real differences in water use.

KEYWORDS: *Fertilizer response (forest tree), lodgepole pine,* Pinus contorta.

The author gratefully acknowledges the advice and assistance of J. Edward Dealy in connection with sampling understory vegetation.

INTRODUCTION

Thinning is the most practical method of increasing usable wood production of lodgepole pine (*Pinus contorta* Dougl.) stands in south-central Oregon (Dahms 1971). The possibility of further increases in production of usable wood through thinning plus fertilization is of interest for future timber management planning. Increased growth of lodgepole pine seedlings in growth chambers after nitrogen (N), phosphorus (P), and sulfur (S) fertilization has been reported (Cochran 1972); but I know of only one published result concerning fertilization of lodgepole pine in the field in North America. Linteau (1962) reported on application of magnesium oxide and potassium chloride at rates of 50 and 100 pounds per acre, respectively, both alone and in combination to a 4-year-old lodgepole pine plantation in Quebec. After the second growing season, the double treatment produced significant increases in growth over other treatments. Also "Mg-treated plots were better than K-treated, and K-treated were better than control." Lodgepole pine has been planted on peats in Great Britian and Norway where responses to phosphorus (Neustein 1962, Lines 1968), to nitrogen and phosphorus (Dickson 1965), and to potassium, phosphorus, and nitrogen (Baldwin 1967, Meshechok 1967) have been recorded.

METHODS OF STUDY

In a preliminary greenhouse experiment, lodgepole pine seedlings grown on soil material from a Lapine AC horizon responded favorably to additions of nitrogen, phosphorus, and sulfur, but boron (B) reduced growth over the ranges and combinations of elements tested.[1/] Maximum seedling response in the incomplete factorial experiments was equivalent to additions of N, P, and S of 600, 300, and 90 pounds per acre,[2/] respectively. Although these amounts seem high for field application, I decided to see how these rates would influence growth of larger trees in the field.

Ten 1/10-acre plots (1- by 1-chain) surrounded by a buffer strip one-half chain wide were established in a pole-size stand located on the Chemult District of the Winema National Forest (section 13 of R. 9 E., T. 28 S. and section 18 of R. 10 E., T. 28 S.). Elevation of the study area is about 5,300 feet. Precipitation averages 26.6 inches per year in Chemult, 11 airline miles west of the stand; and summers are very dry (Franklin and Dyrness 1973). The plots are on a north by northwest aspect, and slopes are less than 5 percent. The understory community is antelope bitterbrush (*Purshia tridentata*)/western needlegrass (*Stipa occidentalis*). The stand, which was established after a fire, lies directly adjacent to an upslope stand of ponderosa pine (*Pinus ponderosa* Laws.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) with a snowbrush (*Ceanothus velutinus*) understory. The Lapine soil, a Typic Cryorthent, developed on deep pumice; it has A1, AC, C1, and C2 horizons (table 1). Roots are concentrated in the A1 and AC horizons. The stand was thinned in the winter of 1966-67 when it was about 40 years old.

Table 1.--*Some properties of the Lapine soil at the study site*[1/]

Horizon	Depth	pH	P	B	Extractable cations				Total N	O.M.[2/]	S	C.E.C.[3/]
					K	Ca	Mg	Na				
	Inches		- p/m -		- - - meq/100 g - - -				- - Percent - -		p/m	meq/100 g
A1	0-2	6.2	7	0.33	124	3.0	0.20	0.50	0.13	17.8	2.8	12.6
AC	2-19	6.5	5	.45	72	2.1	.20	.81	.05	.29	2.7	8.1
C1	19-37	6.6	3	.16	48	.6	.16	.37	.01	.77	.8	4.6
C2	37-72	6.5	3	.23	44	.7	.20	.17	.005	.10	.6	4.6

[1/] Analyses were performed by the Oregon State University soil testing laboratory, Corvallis, by its methods (Roberts et al. 1971).

[2/] O.M. = organic matter.

[3/] C.E.C. = cation exchange capacity.

[1/] Data from this experiment were lost in a fire which destroyed the Silviculture Laboratory in Bend, Oregon, on January 15, 1974.

[2/] Metric unit conversion factors are listed at end of text.

Five of the plots were randomly chosen for fertilization. S was applied as ammonium sulfate (21-0-0, 24-percent S), additional N was added as urea (45-0-0), and P was applied as treble superphosphate (0-45-0) in late October 1970. Every tree in each plot was measured with a Barr and Stroud optical dendrometer.[3/] These dendrometer measurements were subjected to an STX-Fortran-4 program (Grosenbaugh 1967) to calculate the initial stand parameters shown in table 2. Table 2 does not include one tree lost to snow breakage the first winter

Table 2.--*Some initial stand parameters for fertilized and control plots*

Plot number	Basal area	Bole area[1/]	Volume[1/]	Average height	Average diameter[2/]	Trees per acre
	Square feet per acre		Cubic feet per acre	Feet	Inches	Number
Fertilized:						
9	14.6	2,266	284	26.7	4.9	104
7	21.4	4,175	574	36.1	6.4	151
10	30.3	4,705	486	35.2	6.4	139
5	35.7	6,745	801	36.1	6.3	211
1	42.4	7,329	790	42.1	6.3	164
Control:						
6	16.6	3,140	229	26.7	4.1	170
8	31.2	5,333	509	34.6	5.7	160
4	37.7	5,958	619	36.2	6.3	181
3	38.4	6,668	708	39.6	6.3	170
2	51.1	9,275	966	40.5	6.5	221

[1/] Values do not include bole areas and volumes of 1-foot stumps.

[2/] This diameter is the actual mean diameter and is not the diameter derived from the average basal area.

after plot establishment or four trees accidentally destroyed when the thinning slash was tomahawked[4/] 2 years after plot establishment.

Grass production was determined by clipping three 2- by 10-foot transects randomly located on each plot in late summer. Brush production was not determined because trial sampling indicated that the variation in brush production between individual transects was so large that the entire plot would have to be clipped for an adequate sample. Besides needlegrass, bottlebrush squirreltail grass (*Sitanion hystrix*) was found in the plots.

Soil water use down to 5-foot depth was estimated during the 1974 growing season with a neutron probe. Three access tubes were placed in each plot. Each tube was located in the center of a tree opening having a diameter equivalent to the average tree spacing within the plot. Soil water contents were

[3/] Mention of companies or products by name does not constitute an endorsement by the U.S. Department of Agriculture.

[4/] Tomahawking is a method for reducing fire hazard in slash by mechanical crushing with an implement called a "Tomahawk" mounted on the front of a crawler tractor (Dell and Ward 1969).

first measured on May 28 right after the late snowmelt, and the last measurements were taken on October 1, 1974, before the fall rains started.

Four growing seasons after treatment every tree in each plot was again measured with an optical dendrometer (table 3). These measurements were compared with initial measurements (table 2) to determine annual growth rates for the 4-year period. Annual growth rates were then subjected to analysis of covariance (with initial basal area as the covariate) to determine if growth rates were increased by fertilization. To test treatment effects on grass production and water use, t-tests were used after initial analysis showed that these factors did not vary with stand basal area or any other measured variable except treatment.

Table 3.--*Some stand parameters for fertilized and control plots four growing seasons after beginning of study*

Plot number	Basal area	Bole area[1/]	Volume[1/]	Average height	Average diameter[2/]	Trees per acre
	Square feet per acre		Cubic feet per acre	Feet	Inches	Number
Fertilized:						
9	21.9	2,935	322	27.9	6.1	100
7	32.2	5,394	582	38.6	6.5	130
10	38.6	5,717	667	38.3	7.2	130
5	50.9	8,662	908	38.9	6.6	210
1	54.5	8,944	1,091	45.9	7.9	160
Control:						
6	21.9	3,690	291	28.1	4.7	170
8	35.5	6,156	637	37.2	6.5	160
4	43.9	6,792	762	38.1	7.0	160
3	45.4	7,805	863	41.4	6.9	170
2	58.2	10,432	1,136	42.5	6.9	220

[1/] Values do not include bole areas and volumes of 1-foot stumps.

[2/] This diameter is the actual mean diameter and is not the diameter derived from the average basal area.

Patterns of radial wood growth and needle length changes were determined at the end of the fourth growing season from increment borings at 4.5 feet and from measurements of needle lengths on branches which could be reached from the ground where distinct years of development could be determined. These measurements were made on trees in the buffer strips of single control and fertilized plots having the highest initial basal areas. Measurements were made on 10 trees for the fertilized plot and 5 trees for the nonfertilized plot; t-tests were used to assess influence of fertilization on radial growth and needle length.

RESULTS

Regression lines relating annual growth of volume, bole area, and basal area to initial basal area were significantly higher for fertilized plots (figs. 1, 2, and 3 and table 4). However, average height growth for the fertilized trees, 0.6 foot per year, was not significantly greater than the 0.5 foot per year average for the nonfertilized trees (table 4).

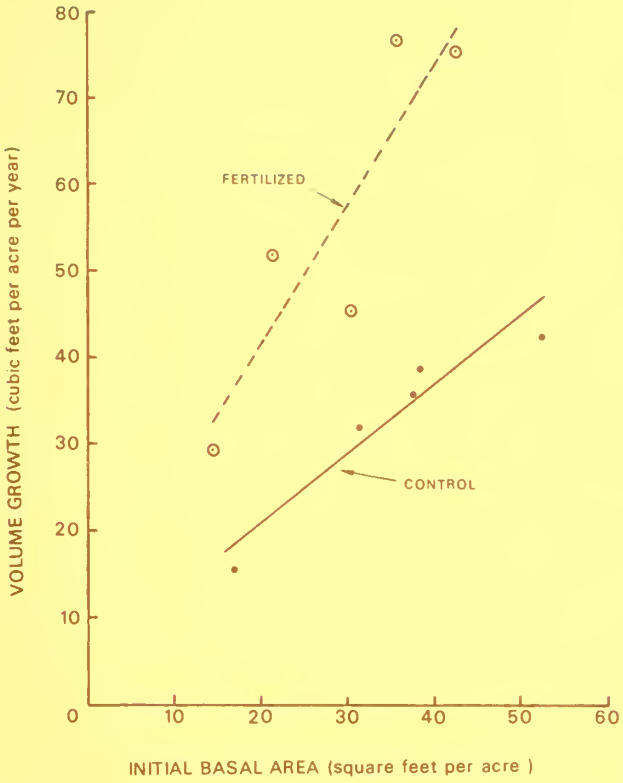


Figure 1.--Annual volume growth as a function of initial basal area. Differences in growth between fertilized and control plots are significant at the 1-percent level of probability. Straight lines represent calculated regressions accounting for 79 percent (fertilized) and 92 percent (control) of the variation in growth.

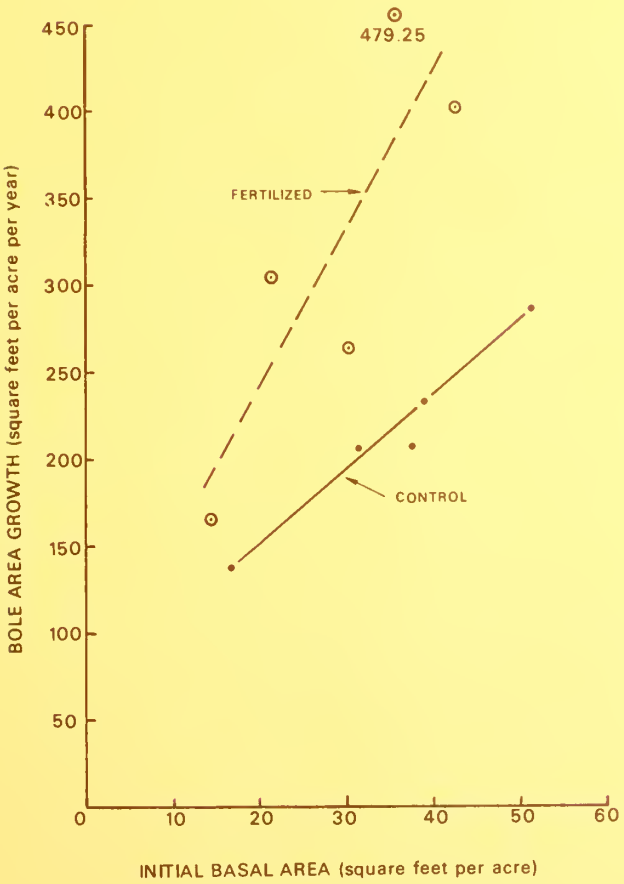


Figure 2.--Annual bole area growth as a function of initial basal area. Differences in growth between fertilized and control plots are significant at the 5-percent level of probability. Straight lines represent calculated regressions accounting for 66 percent (fertilized) and 96 percent (control) of the variation in growth.

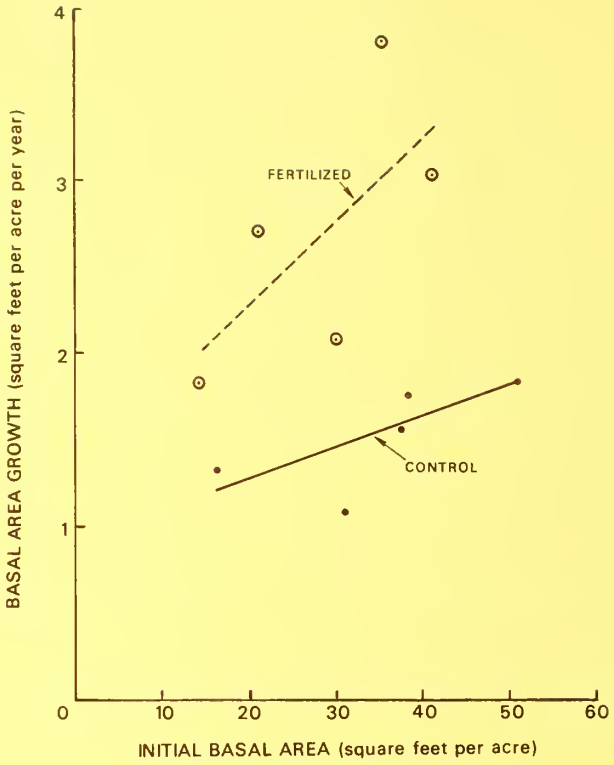


Figure 3.--Annual basal area growth as a function of initial basal area. Differences in growth between fertilized and control plots are significant at the 5-percent levelof probability. Straight lines represent calculated regressions accounting for 46 percent (fertilized) and 47 percent (control) of the variation in growth.

Table 4.--*Annual basal area, bole area, volume, and height growth during four growing seasons*

Plot number	Basal area	Growth per acre per year of bole area[1/]	Volume	Average height growth per year per tree
	- - - - Square feet per acre - - - -		Cubic feet per acre	Feet
Fertilized:				
9	1.825	167.25	29.5	0.3
7	2.7	304.76	52.0	.65
10	2.075	253.00	45.3	.525
5	3.8	479.25	76.8	.725
1	3.025	403.75	75.3	.975
Average	2.685	321.60	55.8	.635
Control:				
6	1.325	137.5	15.5	.35
8	1.075	205.75	32.0	.65
4	1.55	208.5	35.8	.475
3	1.75	234.25	38.8	.45
2	1.775	289.25	42.5	.5
Average	1.495	215.05	32.9	.485

[1/] Stump growth (below 1 foot) is not included.

Grass production was increased by fertilization:

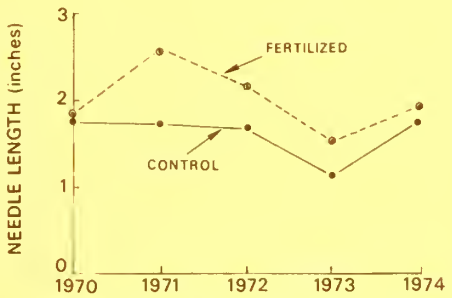
Treatment and year	Treatment averages	Plot ranges
	(Dry weight (lb/acre))	
Control, 1971	7.4	5.3 - 9.3
Fertilized, 1971	37.2	19.7 - 114.0
Control, 1974	3.7	0 - 12.7
Fertilized, 1974	68.0	18.6 - 183.5

Data for grass production during the 1972 and 1973 growing seasons were lost in the fire mentioned in footnote 1.

Water use from the upper 5 feet of soil in 1974 averaged 6.6 inches for the fertilized plots and ranged from 5.6 to 8.1 inches for individual plots. This use was not significantly greater than the use in the control plots (average 5.6 inches, range 4.2 to 7.9 inches).

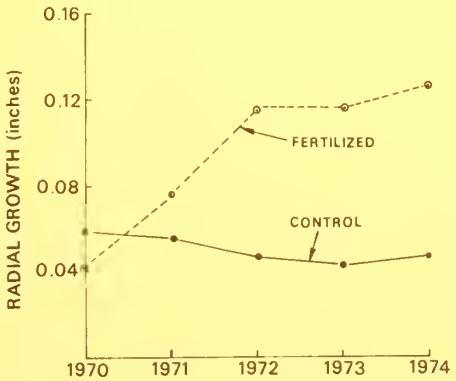
Needle length on fertilized trees increased markedly the first season after application (1971), decreased in 1972 and 1974 and even dropped below the prefertilization length in 1973, a very dry year (fig. 4). Needles for the

Figure 4.--Needle length for 1 year before and 4 years after treatment. Needles on fertilized trees were significantly longer than needles on control trees at the 1-percent level of probability in 1971 and 1972 and at the 5-percent level in 1973.



trees on the control plot were consistently shorter for 1971, 1972, and 1973. Radial growth of the fertilized trees increased the first season after treatment and continued to increase each succeeding year except for the dry year 1973 (fig. 5). Even in 1973 the difference in radial growth between fertilized and control trees appears slightly greater than in 1972. On the control plot, radial growth appears to be gradually declining.

Figure 5.--Radial growth for 1 year before and 4 years after treatment. Differences between the two treatments are significant at the 1-percent level of probability for 1972, 1973, and 1974.



DISCUSSION AND CONCLUSIONS

Although the heavy applications of fertilizer used in the study may never be practical in forest management, the study shows that production of wood and grass in thinned stands can be greatly increased, at least for 4 years, by fertilization. Future remeasurements are needed to determine length of response, but radial growth patterns (fig. 5) indicate that the response will continue beyond 4 years.

Brix and Ebell (1969) found that N-fertilization of 20-year-old Douglas-fir increased leaf area. Later, Brix (1971) reported the N-fertilization increased photosynthetic capacity of new shoots but not older shoots of Douglas-fir even though both chlorophyll and nitrogen concentration increased in older leaves. Total transpiration would also be expected to increase with increased leaf surface area. Further, N-supplied bean plants have been reported to have higher transpiration rates per unit leaf area than N-deficient plants under conditions of high soil moisture (Shimishi 1970).

Patterns of needle length and radial growth (figs. 4 and 5) show that fertilization caused a rapid expansion of needle surface area and photosynthetic capacity the first growing season after treatment. Since lodgepole needles stay on the tree for at least 4 years, the decrease in needle length after 1971 is not necessarily accompanied by a decrease in total needle surface area for the following years. In fact, patterns of radial growth (fig. 5) indicate that the photosynthetic capacity of fertilized lodgepole pine increased every year since treatment except during the dry year 1973. Fertilization did not cause a clear-cut increase in soil water use, but sampling error may have masked real differences. Perhaps total needle surface area and photosynthetic capacity remain constant for a given set of environmental conditions as proposed by Brix (1971). If so, the increased photosynthetic capacity evident from the radial growth pattern suggests increased availability of nutrients for each succeeding year since application except 1973.

The high price and limited supply of fertilizers present a questionable future for fertilization of low-producing stands of lodgepole pine. However, as timber management intensifies, questions about fertilization will continue to arise. Results of this and related studies are necessary to relate soil test values to growth responses, to determine duration of fertilizer response, to determine fertilizer combinations necessary for given growth responses, and to determine the influence of fertilizers on understory vegetation and soil water use.

METRIC CONVERSION FACTORS

1 pound/acre	= 1.121 kilograms/hectare
1 acre	= 0.405 hectare
1 chain	= 20.116 8 meters
1 foot	= 0.304 8 meter
1 inch	= 2.54 centimeters
1 square foot/acre	= 0.229 568 square meter/hectare
1 cubic foot/acre	= 0.069 972 cubic meter/hectare
1 mile	= 1.61 kilometers

LITERATURE CITED

Baldwin, E.
1967. A fertilizer trial on deep peat. Scott. For. 21(4):229-231.

Brix, H.
1971. Effects of nitrogen fertilization on photosynthesis and respiration in Douglas-fir. For. Sci. 17:407-414.

Brix, H., and L. F. Ebell
1969. Effects of nitrogen fertilization on growth, leaf area, and photosynthesis rate in Douglas-fir. For. Sci. 15:189-196.

Cochran, P. H.
1972. Temperature and soil fertility affect lodgepole and ponderosa pine seedling growth. For. Sci. 18:132-134.

Dahms, Walter G.
1971. Growth and soil moisture in thinnned lodgepole pine. USDA For. Serv. Res. Pap. PNW-127, 32 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Dell, John D., and Franklin R. Ward
1969. Reducing fire hazard in ponderosa pine thinning slash by mechanical crushing. USDA For. Serv. Res. Pap. PSW-57, 9 p., illus. Pac. Southwest For. & Range Exp. Stn., Berkeley, Calif.

Dickson, D. A.
1965. The effect of nitrogenous and phosphatic fertilizers on the growth of checked trees on deep peat. North. Irel. Minist. Agric. Rec. Agric. Res. 14(2):61-71.

Franklin, Jerry F., and C. T. Dyrness
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Grosenbaugh, L. R.
1967. STX-FORTRAN-4 PROGRAM for estimates of tree populations from 3P sample-tree-measurements. USDA For. Serv. Res. Pap. PSW-13 (rev.), 77 p. Pac. Southwest For. & Range Exp. Stn., Berkeley, Calif.

Lines, Roger
1968. The silviculture of lodgepole pine. Report of the silvicultural group for 1966-67. Scott. For. 22(2):91-108.

Linteau, Andre
1962. Some experiments in forest soil fertilization. Que. Univ. Laval Fonds de Rech. For. Bull. No. 5:25-37.

Meshechok, Boris
1967. Om startgjodsling ved skogkultur pa myr (lnitial fertilization when afforesting open swamps). Det Nor. Skogforsoksves. Rep. Norw. For. Res. Inst. 25(1), No. 87:1-140. Norw. For. Res. lnst., Vollebekk, Norw. (English summary.)

Neustein, S. A.
1962. The effect of phosphate, applied at planting, on a crop at the pole stage on upland heath. G. B. For. Comm. Rep. For. Res. 1962:141-145.

Roberts, S., R. U. Vodraska, M. D. Kauffman, and E. H. Gardner
1971. Methods of soils analysis used in the soil testing laboratory at Oregon State Univ. Agric. Exp. Stn. Spec. Rep. 321, 39 p. Oreg. State Univ., Corvallis.

Shimishi, D.
1970. The effect of nitrogen supply on transpiration and stomatal behavior of beans (*Phaseolus vulgaris* L.). New Phytol. 69:405-412.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-248 May 1975

SWEETNESS OF HUCKLEBERRIES NEAR MOUNT ADAMS, WASHINGTON

by

Don Minore, *Plant Ecologist*

and

Alan W. Smart, *Forestry Technician*

APR 19 1976

ABSTRACT

Soluble solid contents of shaded and exposed huckleberry fruits were sampled throughout the 1974 berrypicking season near Mount Adams, Washington. No significant exposure differences were observed, but huckleberries were sweetest after beargrass (Xerophyllum tenax *(Pursh) Nutt.) began shedding seeds.*

Keywords: Berry crop, thin-leaved huckleberry, *Vaccinium membranaceum.*

INTRODUCTION

Thousands of berrypickers visit northwestern huckleberry fields every autumn, most of them to pick the fruit of *Vaccinium membranaceum* Dougl. (the thin-leaved huckleberry). Most search for large, sweet berries. Although the sugar content of most fruits and berries increases with maturity and exposure to sunlight, there is no reliable information indicating when or where the sweetest wild huckleberries can be found. Huckleberry quality seems to vary in both space and time.

Information on berry sweetness is available for some of the eastern *Vaccinium* species. Barker et al.[1/] measured sugar content in *V. angustifolium*

[1/] W. G. Barker, A. Wood, and W. B. Collins. Sugar levels in fruits of the lowbush blueberry (*Vaccinium angustifolium*) estimated at four physiological ages. Nature 198: 810-811, 1963.

and *V. myrtilloides* fruits from several clones of each species. They observed no significant clonal differences but found that the concentration of sugar increased with physiological age of the berries in both species. Uhe[2/] determined the approximate sugar content of cultivated Jersey blueberries by testing for soluble solids with a hand refractometer. He found that the berries were sweeter later in the picking season.

Many western berrypickers assume that western wild huckleberries, like eastern species, produce sweeter fruits later in the season. Others favor exposed, open-grown huckleberries over those grown in the shade. The observations reported here were taken to determine the optimum picking period and shade conditions for obtaining sweet berries of *V. membranaceum* in a single, heavily used huckleberry field in 1974.

METHODS

A representative 20 pairs of small circular plots were selected and marked in the Sawtooth huckleberry field near Mount Adams, Washington. Each plot was one two-hundredth acre in size, and each supported several *V. membranaceum* bushes. One plot in each pair was located in a shady area underneath trees. The other was located in a more exposed area nearby, where overstory canopy was less dense or absent. Overstory canopy densities were measured at each of the 40 plots with a spherical densiometer held just above the huckleberry bushes. Mean canopy density over the shaded plots was 87 percent (range: 66-97 percent). Mean canopy density over the exposed plots was 22 percent (range: 7-41 percent).

Beginning in late August, when berries first began to ripen in the Sawtooth field, soluble solids content (an approximate measure of sugar content and berry sweetness) was sampled at biweekly intervals on all 40 plots.[3/] Dark, non-red berries on each plot were picked and crushed in a garlic press. (Berries darken and become less red as they ripen). Resulting juice was tested in the field with a hand refractometer.[4/] Two samples of berries were collected from each plot at each sampling date. The resulting refractometer readings (percent soluble solids expressed in degrees Brix) were averaged to give a single soluble solids content for that plot.

Berries were sampled on four dates in 1974: August 27, September 10, September 25, and October 10. Yearly weather variations create variations in ripening between years, and calendar dates are not reliable indicators of phenological events. Therefore, phenological observations of common plant species were recorded at each sampling so that any seasonal differences in berry sweetness could be related to seasonal vegetation changes. Among these plants was beargrass (*Xerophyllum tenax* (Pursh) Nutt.).

[2/] George Uhe, Jr. The influence of certain factors on the acidity and sugar content of the Jersey blueberry. Master's thesis, Oregon State Univ., Corvallis, 40 p., 1957.

[3/] For practical purposes, the percent of soluble solids is a close approximation of sugar content. The soluble solids other than sugar constitute only a small fraction of the cell sap in cultivated blueberries, melons, squashes, and other horticultural products (Uhe 1957--see footnote 2).

[4/] American Optical refractometer model 10423, for field determination of dissolved sugar content of fruits and vegetables. (Mention of companies or products by name does not constitute an endorsement by the U.S. Department of Agriculture.)

Differences in measured soluble solids content between exposed plots, shaded plots, and picking dates were investigated through a randomized block split-plot analysis of variance in which shading was the main plot variable. Where significant differences were present (probability < 0.05), they were identified with Scheffe's multiple range tests.

RESULTS AND DISCUSSION

There was little apparent relationship between canopy density and berry sweetness. Soluble solid contents varied greatly, being higher where shaded in some plot pairs, higher where exposed in others. Although average soluble solids content for exposed plots was slightly higher than that for shaded plots (table 1), the difference was not statistically significant. Spring snowmelt patterns may obscure the effect of shade. The winter snowpack melts sooner under isolated groups of trees than in the open huckleberry field. *Vaccinium* plants under these trees, though shaded, apparently have a longer growing season than plants in more exposed locations. They develop earlier in the spring, becoming green and leafy while plants in nearby exposed locations are still dormant and bare.

Table 1.--*Soluble solids in shaded and exposed huckleberry fruits, by picking date and beargrass phenology*

Picking date	Beargrass phenology	Average soluble solids content		Average, all plots[1/]
		Shaded plots	Exposed plots	
		- - *Degrees Brix* - - -		
August 27	Fruits all green, with half the petal remnants white	11.84	11.86	11.85 a
September 10	Half the fruits brown, no white petal remnants	11.16	12.45	11.80 a
September 25	Fruits opening and shedding seeds	14.50	15.58	15.04 b
October 10	Fruits all open	15.88	16.52	16.20 b
Average, all dates[1/]		13.34 c	14.10 c	

[1/] Values followed by the same letter are not significantly different. There were no significant date x shade interactions.

[2/] Degrees Brix = percent sugar content for pure sucrose solutions. Where other soluble compounds are present, as in berry juice, the Brix value may be slightly higher or lower than percent sugar content. For our purposes, these differences can be ignored. Higher Brix values indicate higher soluble solids content, higher sugar content, and sweeter berries.

A late snowpack and cool spring weather delayed ripening of huckleberries in both shaded and exposed plots in 1974. Berries were just beginning to ripen when the first sample was picked on August 27. Soluble solids content was low

in this first sample (table 1). Many berries appeared to be ripe by September 10, but their soluble solids content remained low. The berries were much sweeter on September 25. This increase in soluble solids content between September 10 and 25 was highly significant. It occurred after most recreational berrypicking had ended. Further increase in soluble solids content was not statistically significant, and by October 7 many berries were beginning to soften and shrivel.

Phenological observations of most plant species in the huckleberry field were rather inconclusive, because the individual plants of most species varied widely in rate of development. Fortunately, beargrass development did not vary noticeably among individual plants. Flowering, fruiting, and seed dispersal occurred uniformly in the many individuals observed. *Xerophyllum* and *V. membranaceum* occur together throughout the Sawtooth huckleberry field, and the two species commonly are associated in Oregon and Washington. Beargrass phenology seemed to be an excellent indicator of huckleberry sweetness. The soluble solids content of *V. membranaceum* fruits was highest after *Xerophyllum* began shedding seeds (table 1).

Three conclusions may be drawn for the 1974 season:

1. Huckleberries became sweetest after most berrypickers had left the Sawtooth huckleberry field.
2. Berry sweetness was not affected significantly by shading.
3. Shedding of beargrass seed seemed to be a reliable indicator of huckleberry sweetness.

As mentioned earlier, 1974 had a late spring; and we are not sure these conclusions will be valid every year. If beargrass indeed does respond to weather variations similarly to huckleberry, it may prove to be a useful indicator of maximum huckleberry sweetness regardless of seasonal variation between years.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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SUGAR PINE SEEDLINGS NOT PROTECTED FROM BLISTER RUST BY CHEMOTHERAPEUTANTS

by

George M. Harvey, *Plant Pathologist*

ABSTRACT

None of several types of chemotherapeutants applied before inoculation (antibiotics, metallic salts, systemic fungicides) prevented infection of sugar pine seedlings by white pine blister rust. DMSO (dimethyl sulfoxide) did not enhance the action of any material with which it was applied.

Keywords: Sugar pine, *Pinus lambertiana*, white pine blister rust, *Cronartium ribicola*, fungicides.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Since 1965 we have installed eight nursery tests of chemotherapeutants against white pine blister rust (*Cronartium ribicola* Fisch.) on sugar pine (*Pinus lambertiana* Dougl.) seedlings. This has been an empirical search among systemic fungicides and other compounds which might impart either temporary (up to 3 years) or lasting (5 or more years) protection to the seedlings from blister rust. Materials used have ranged from simple nickel salts reported by Ram (1964) as effective against blister blight (*Exobasidium vexans* Massee) on tea plants grown in nickel-augmented soil to the systemic oxathiin fungicides reported by Powelson and Shaner (1966), Hardison (1966), and von Schmeling and Kulka (1966). This note briefly describes the results of these tests.

METHODS AND MATERIALS

Sugar pine 2-0 seedlings, either from refrigerated storage or directly from the seed beds, were transplanted in May or June at a test site at the nursery. Each of the eight tests consisted of a unit of sixty 2- x 2-ft (0.6- x 0.6-m) cells arranged in four rows of 15 cells each. A single 2-ft-wide (0.6-m) longitudinal path separated rows two and three of each unit. Each cell was planted with 13 sugar pine seedlings. All seedlings were Rogue River National Forest seed source, Union Creek or Prospect District, 3,000- to 5,000-ft (914- to 1524-m) elevation.

Chemicals were applied to each cell in a completely randomized design in July or August of the transplanting year. Each of the eight treatments and two controls were replicated six times per unit. Four methods were used to apply the chemicals. These were:

Root soak.--Seedlings were placed in solutions and then outplanted.

Soil drench.--Solutions of chemicals were flooded onto the surface of each cell and contained until absorbed by the soil.

Foliar spray.--Seedlings were either sprayed to the point of runoff or seedlings and soil surface were sprayed with a premeasured dose. Application was made with gardentype pump-up or laboratory-type Freon-pressured sprayers. All sprays were confined within a 2-ft (0.6-m) cubic "spray box" to prevent drifting to adjacent cells.

Soil amendment.--Dry chemical dosage for each cell was thoroughly mixed with 1 kg (2.2 lb) of dry, white, washed mason's sand, spread evenly on each cell, and then worked gently into the top inch (2.5 cm) of soil with a hand cultivator.

The first artificial inoculation with blister rust was made in August or September of the planting and treatment year. The first four units (treatments of 1965 and 1966, table 1) were inoculated twice (2 consecutive years), while the last four units (treatments of 1967 and 1969, table 1) were inoculated three times (3 consecutive years). Inoculations were made in large, tentlike movable chambers of canvas and polyethylene film temporarily erected over each 60-cell unit. Interior and exterior sprinkler systems maintained temperatures below 70° F (21.1° C) and relative humidity above 95 percent through the 72-hour inoculation period. Sporidia, cast from infected *Ribes* cuttings distributed among the seedlings, were monitored during each inoculation on 10 spore-trap slides per unit. One set of controls was inoculated the first inoculation, the second set the second inoculation, and both sets the third inoculation (last four units only--treatments of 1967 and 1969, table 1). Controls were covered by polyethylene film. Treatment effectiveness was evaluated annually

Table 1.--*Summary of chemical treatments of sugar pine seedlings, Wind River Nursery, Washington, 1965-69*

Year treatment was:		Chemical, adjuvant, and application method	Concentration	Best treatment[1]	Range of blister rust infection	Range of treatment phytotoxic mortality
Applied	Evaluated			Number and Percent	- - - Percent - - - -	
1965	1968	Untreated controls	--	--	97-100	--
1965	1968	Phytoactin L-318:[2] *12, 24-, 36-hour root soak	100 p/m	1/49 = 2.0	98-100	25-35
1965	1968	Cycloheximide semicarbazone:[3] soil drench	100, 200, *300 p/m	1/8 = 12.5	88-100	35-90
1965	1968	Phleomycin: 24-hour root soak	100 p/m	1/67 = 1.4	99	13
1965	1968	Cycloheximide semicarbazone:[3] 24-hour root soak	10 p/m	0/0 = 0	0	100
1965	1968	Untreated controls	--	--	97- 99	--
1965	1968	Nickel ammonium sulfate: soil drench	5, 10, *15 g/ft^2 (0.3 m^2)	2/64 = 3.1	97-100	0- 2
1965	1968	Nickel nitrate: soil drench	5, 10, *15 g/ft^2 (0.3 m^2)	3/59 = 5.1	95-100	0-12
1965	1968	Phleomycin: foliar spray	100, 200 p/m	0/74 = 0	100	0
1966	1969	Untreated controls	--	--	99-100	--
1966	1969	Nickel chloride + DMSO:[4] foliar spray	2.5, *5% (w/v)	1/66 = 1.5	98- 99	5-14
1966	1969	Cupric chloride + DMSO:[4] foliar spray	*1.25, 2.5% (w/v)	2/72 = 2.8	97-100	8-10
1966	1969	Naphthalene acetic acid + DMSO:[4] foliar spray	1.5, *3% (w/v)	4/10 = 40.0	60- 93	25-87
1966	1969	Iodine + DMSO:[4] foliar spray	1.5, 3% (w/v)	0/74 = 0	100	5
1966	1969	Untreated controls	--	--	96-100	--
1966	1969	Oxathiin F-461-W:[5] foliar spray	*1, 25, 50, 100 lb active/acre[6]	1/69 = 1.4	98-100	0-12
1966	1969	Oxathiin F-461-ST:[5] soil drench	1, 25, 50, *100 lb active/acre[6]	4/76 = 5.3	95-100	0- 5
1967	1971	Untreated controls	--	--	97	--
1967	1971	Nickel nitrate + DMSO:[4] foliar spray	*0.6, 1.2, 2.5, 5% (w/v)	2/59 = 3.4	0-100	16-100
1967	1971	Nickel nitrate: foliar spray	*0.6, 1.2, 2.5, 5% (w/v)	2/60 = 3.3	97-100	13-99
1967	1971	Untreated controls	--	--	99-100	--
1967	1971	Nickel nitrate: soil drench	15, 20, *25, 30 g/ft^2 (0.3 m^2)	1/9 = 11.1	89-100	26-96
1967	1971	Nickel nitrate: soil amendment	15, *20, 25, 30 g/ft^2 (0.3 m^2)	8/63 = 12.7	87- 95	11-38
1969	1973	Untreated controls	--	--	99	--
1969	1973	Oxathiin F-461-W:[5] foliar spray	1, *25, 50, 100 lb active/acre[6]	2/72 = 2.8	97-100	0- 3
1969	1973	Oxathiin F-461-ST:[5] soil amendment	1, 25, 50, 100 lb active/acre[6]	0/75 = 0	100	0- 3
1969	1973	Untreated controls	--	--	100	--
1969	1973	Benlate-WP[7] + DMSO:[4] foliar spray	1, 25, 50, 100 lb active/acre[6]	0/75 = 0	100	0- 1
1969	1973	Benlate-WP[7] soil amendment	1, *25, 50, 100 lb active/acre[6]	1/73 = 1.4	99-100	0- 1

[1] Best treatment is largest number of surviving uninfected sugar pine seedlings (numerator) in relation to number planted minus mortality from treatment, sampling for nickel analyses (1967 nickel treatments only), or other causes; blister rust is denominator. Best treatment indicated by asterisk (*); lack of asterisk indicates no best treatment.

[2] Supplied by PL Biochemicals, Inc., Milwaukee, Wisconsin 53205.

[3] Supplied by the Upjohn Co., Kalamazoo, Michigan 49001.

[4] DMSO and ready-to-apply solutions furnished by Crown Zellerbach Corp., Camas, Washington 98607.

[5] Oxathiin F-461-W and F-461-ST = 2,3-Dihydro-5-carboxanilido-6-methyl-1,4-oxathiin-4, 4-dioxide supplied by U.S. Rubber Co., Naugatuck, Connecticut 06771.

[6] 1, 25, 50, 100 lb active/acre = 1.12, 28.02, 56.04, 112.08 kg active/hectare.

[7] Benlate = benomyl = methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate supplied by E. I. duPont de Nemours & Co., Wilmington, Delaware 19898.

NOTES.--Complete test results will be furnished on request by the Forestry Sciences Laboratory, Corvallis, Oregon 97331.

Mention of trade names is for information only and does not imply endorsement by the U.S. Department of Agriculture.

on the basis of uninfected trees. Year of final evaluation is given in table 1.

RESULTS AND DISCUSSION

Seedling response, as indicated either by damaging *C. ribicola* infection or by high treatment mortality, signifies that all the treatments were either ineffective or too phytotoxic to be useful (table 1). For example, the oxathiin and Benlate treatments (1966 and 1969) were neither phytotoxic nor particularly effective. In contrast, a 3-percent naphthalene acetic acid solution plus DMSO applied as a foliar spray (1966 treatment) was 40 percent effective in preventing *C. ribicola* infection. However, this 40-percent effectiveness is based upon 4 uninfected seedlings from a total of 10 which survived the treatment (78 planted and treated). DMSO (dimethyl sulfoxide) did not enhance the protective action of any material with which it was applied. Tests of hypotheses were not appropriate due to lack of useful protective response from the treatments.

In May 1967, the 1965 application of nickel nitrate at 15 grams per square foot (0.3 m^2) had a very promising infection level of only 35 percent (21/60) compared with a 100-percent infection level (74/74) for the controls. However, 1 year later (May 1968), the infection level had increased to 95 percent. Similar results were obtained from increased nickel dosages made in 1967. Analyses for nickel of the first-year soil samples from the 1967 applications indicated that under the conditions of our tests, nickel leached from the seedling root zone very rapidly. These results suggest that nickel salts may provide transitory protection from *C. ribicola* but that frequent reapplications would be necessary for continuous protection. Such reapplication and the risk of serious phytotoxicity make nickel salts impractical for field use.

It is possible only to speculate why oxathiin and Benlate were not effective against *C. ribicola* under the conditions of our tests. Perhaps an effective application rate for a one-time application was not reached, or perhaps each fungicide needs to be continuously available for uptake by the plant root system for effective protection. The low phytotoxicity of these two materials suggests that greatly increased application rates might be effective; however, we have no plans for further tests. None of the materials tested here in the concentrations used can be recommended for control of *C. ribicola* on sugar pine seedlings.

LITERATURE CITED

Hardison, John R.
1966. Systemic activity of two derivatives of 1,4-oxathiin against smut and rust diseases of grasses. Plant Dis. Rep. 50: 624.

Powelson, R. L., and G. E. Shaner
1966. An effective chemical seed treatment for systemic control of seedling infection of wheat by stripe rust (*Puccinia striiformis*). Plant Dis. Rep. 50: 806-807.

Ram, C. S. Venkata
1964. Resistance of tea plants to blister blight in soils augmented with nickel. Nature 204(4964): 1227.

von Schmeling, B., and M. Kulka
1966. Systemic fungicidal activity of 1,4-oxathiin derivatives. Science 152: 659-660.

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ALASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

.79 PNW-250

PNW-250 June 1975

PHELLINUS (PORIA) WEIRII ROOT ROT IN DOUGLAS-FIR-ALDER STANDS 10-17 YEARS OLD [1/]

by

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ABSTRACT

Red alder growing in even-aged mixture with Douglas-fir did not reduce initial losses to *Phellinus weirii* 10- to 17-year-old Douglas-fir plantations. The ability of alder to reduce later losses from lateral spread within the stand was not examined. *P. weirii* is creating openings in these young stands with 3 percent of the trees already dead in one case. The symptoms and distinguishing features of *P. weirii* infection on young trees are described.

Keywords: Root rot, *Phellinus* (*Poria*) *weirii*, alder, Douglas-fir.

[1/] Research supported by Cooperative Aid Agreement of U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station; Oregon State University; and International Paper Company.

Phellinus weirii (Murr.) Gilb. (*Poria weirii* (Murr.) Murr.), cause of a destructive root rot, attacks most western conifers including Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. The fungus can survive more than 50 years in infected roots and stumps, infecting roots of a new tree generation as they contact old residues (Wallis and Reynolds 1965).

The hypothesis that red alder, *Alnus rubra* Bong., alters the soil environment to the detriment of *P. weirii* has been developed through research and observation in the Northwest but needs further testing in the field. Alder, in addition to not being susceptible to *P. weirii*, produces phenolic and fatty acid compounds which are toxic to the fungus (Trappe 1972, Trappe et al. 1973) and adds nitrogen to the soil. Micro-organisms antagonistic to *P. weirii* increase and *P. weirii* survival decreases in nitrogen-amended soils (Nelson 1970). In addition, limited field data suggest that *P. weirii* damage to pole-size and larger Douglas-fir is less severe in stands mixed with alder than in pure stands (Trappe 1972).

If alder does reduce *P. weirii* damage, it could act in several ways. The presence of alder might simply result in a wider spacing of susceptible trees, resulting in fewer root contacts and less chance for spread. External mycelial growth of *P. weirii* might be prevented or slowed in a soil altered by alder. Alder root exudates or the micro-organisms they stimulate might actually penetrate wood infected by *P. weirii* and kill the pathogen.

The objective of the research described here was to determine whether alder growing in even-aged mixture with Douglas-fir influenced initial infection in a new tree generation by residual infected root systems from the preceding stand.

STUDY AREAS

Four study sites about 48 km west of Corvallis, Oregon, on the Siuslaw National Forest were examined in 1973. Each was a Douglas-fir plantation with a naturally seeded admixture of red alder. The sites had been planted immediately after harvest of mature Douglas-fir stands 10-17 years before examination. Growth ring counts indicated that natural alder had seeded within 1 or 2 years after harvest in each case. The plantations were on north, east, and west aspects and typified by abundance of *P. weirii* root rot, steep slopes, and thick brush. Although three of the plantations had been sprayed with herbicides, the alder was as tall as or taller than the fir and vigorous at the time of examination. Alder in the fourth plantation had been thinned in 1972.

PROCEDURE

Distances from *P. weirii*-infected Douglas-fir and healthy Douglas-fir to alder trees were recorded during field examinations. All trees, living and dead, on a 3.6 ha area of the first plantation (3504-11, table 1) were examined for root infection. *P. weirii* was confirmed as the cause of death or distress on all symptomatic trees by examination of the root collar for characteristic mycelium. Age and height of each infected tree were recorded, together with the distance to each alder within a radius equal to the height of the infected tree. A separate 10-percent sampling using 0.008 ha circular plots on a rectangular grid was conducted for information on the total stand. For each healthy Douglas-fir within a plot, the distance to each alder within a radius equal to the tree's height was recorded.

The other three plantations were sampled along meandering transects following the slope contour, rather

Table 1.--*Proximity of* Poria weirii-*killed and healthy Douglas-fir to red alder in 4 plantations*

Plantation		Infected trees examined	Infected Douglas-fir with alder at distance of:		Healthy Douglas-fir with alder at distance of:	
Number[1/]	Age		< 5 feet	< tree height	< 5 feet	< tree height
	Years	Number	Percent			
1. (3504-11)	12	79	7	31	6	26
2. (3406-22)	10	54	43	57	45	58
3. (3501-24)	17	34	9	35	4	39
4. (3504-3, 4, 71)	12	39	2	26	2	18
Average	13	--	15	38	10	33

[1/] Alsea Ranger District, Siuslaw National Forest code.

than on an area basis. Data on *P. weirii*-infected trees along the transects were gathered as before, and healthy stand information was again based on 0.008 ha plots. A plot was located 10 m along the contour from each *P. weirii*-infected tree or group of trees, and the distances to alders recorded as before.

RESULTS

Table 1 summarizes the information on the four stands. Overall, proximity to alder did not reduce the chances for *P. weirii* infection of Douglas-fir. Of the infected trees, 38 percent had an alder growing within a distance equal to their height, compared with 33 percent of all healthy Douglas-fir trees sampled. The same situation was evident when only red alder growing within 1.52 m of fir trees were considered.

The aboveground indications of *P. weirii* infection included reduced terminal growth and often a bent leader, yellowish to red foliage, and occasionally a "distress" cone crop. Reduced height growth of infected trees started 1 to 3 years before death and was often evident before foliage discoloration.

The crown symptoms are not unique to *P. weirii* infection but indicate trouble of some sort below. This may be nutrient deficiency, girdling by rodents or bears, or attack by any of several root disease organisms. *P. weirii* was easily confirmed in these young trees by examination of the root collar region for the distinctive mycelium. *P. weirii* grows on root surfaces, and scraping the duff layer away revealed the tawny white fungal hyphae covering the roots and often binding soil particles to the roots. Thin brown hyphal crusts were found on some roots. Examination of these roots with a 10× hand magnifier revealed scattered, brown, specialized hyphae called setae. These were much larger than the rest of the hyphae and were positive confirmation of *P. weirii*.

In the plantations examined, 206 of 211 dead or dying trees had *P. weirii* mycelium at the root collar. Three were killed by *Verticicladiella* sp., and two were girdled by rodents.

P. weirii has already created numerous openings in these plantations. Plantation 1, with 810 trees/ha after thinning, had lost 22.8 trees/ha to *P. weirii*. Of these, an average of 8.3 trees/ha (about 1 percent of the stand) first showed *P. weirii* symptoms in the year after thinning. Of the 81 dead or dying trees in this 3.6 ha plantation, 65 occurred in 20 small infection centers on 2 or more trees each. Although the survey technique used in the other three plantations

did not allow expression of results on a tree/ha basis, they appeared to be even more severely damaged than the first.

DISCUSSION

Red alder has not reduced losses to *P. weirii* in these plantations at this stage in stand development. In many cases, especially in plantation 2, *P. weirii* had infected trees growing in the midst of alder clumps, but a *P. weirii*-infected stump from the previous stand was usually within a few feet of the dead tree. Most of the infection of Douglas-fir in these young stands has presumably resulted from root contact with infected roots left from the previous stand, not from root-to-root spread within the current generation.

The failure of alder in even-aged mixture with Douglas-fir to prevent these initial infections from residual material is not surprising, considering the extreme hazard and the short period of time for soil modification. The ability of alder to reduce lateral spread of *P. weirii* within a stand was not tested in this study. The effects of longer periods of plantation mixtures, as well as crop rotation with alder, must be examined before the full potential of red alder as a disease control agent is known.

P. weirii caused nearly all of the mortality found in this study, but elsewhere other pathogens may be encountered more frequently. Two common fungi are easily distinguished from *P. weirii*. *Armillaria mellea* forms a mycelial "fan," or mat of hyphae beneath the bark, not on the root surface, and often causes considerable resin flow at the butt of a tree. *Verticicladiella*, on the other hand, forms no visible mycelium, but cross-sections of infected roots show crescents of brown-black stain. Other fungi may form surface mycelium on roots and the root collar, but these are usually pure white or yellowish, not white with reddish-brown tones like *P. weirii*.

Initial infection of young trees from residual inoculum results in scattered mortality over the area of an old infection center. This may at first appear to be a beneficial natural thinning, and even a 1-percent annual mortality rate would not leave an understocked stand at maturity if the right trees died. Because it spreads from tree to tree over root contacts, however, *P. weirii* mortality results in slowly enlarging, nonstocked holes in the stand.

There are possibilities for controlling *P. weirii* by planting less susceptible species or removing the inoculum, if the problem is recognized at harvest time. If the problem is not recognized until after a new stand is established, fiscal losses can be reduced by recognizing infection centers and avoiding costly operations such as interplanting or precommercial thinning in their vicinity. Although trees can be attacked and killed whenever their roots contact inoculum, mortality may not be evident in a stand for as long as 10 years after planting.

If the final report on plantation establishment is 10 years or more after planting, an assessment of future losses is possible and silvicultural treatments can be planned accordingly.

LITERATURE CITED

Nelson, Earl E.
1970. Effects of nitrogen fertilizer on survival of *Poria weirii* and populations of soil fungi and aerobic actinomycetes. Northwest Sci. 44:102-106.

Trappe, J. M., C. Y. Li, K. C. Lu, and W. B. Bollen.
1973. Differential response of *Poria weirii* to phenolic acids

from Douglas-fir and red alder roots. For. Sci. 19:191-196.

Trappe, James M.
1972. Regulation of soil organisms by red alder--a potential biological system for control of *Poria weirii*. *In* Alan B. Berg (ed.), Managing young forests in the Douglas-fir region. Oreg. State Univ., Sch. For. Symp. 3:35-46.

Wallis, G. W., and G. Reynolds.
1965. The initiation and spread of *Poria weirii* root rot of Douglas-fir. Can. J. Bot. 43:1-9.

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USDA FOREST SERVICE RESEARCH NOTE

PNW-251 August 1975

AN INCREASE IN CONIFER SEEDLING SURVIVAL AND VIGOR ON AN EAST CASCADE SLOPE WITH A SOIL FUMIGANT

by

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ABSTRACT

In small experimental field plantings on the Wenatchee National Forest, the survival of Douglas-fir 2-0 seedlings increased from 45 to 91.9 percent after soil fumigation with methyl bromide. The vigor of both Douglas-fir and ponderosa pine seedlings also improved after fumigation. Biotic factor(s) may be restricting conifer seedling development on some east Cascade slope soils.

Keywords: Soil treatment(-natural regeneration, seedling survival.

Survival of newly planted conifer seedlings on the east slopes of the Cascades is frequently lower than desired. Many factors influence survival during the first year, including climate, availability of soil water and nutrients, rodent activity, competitive vegetation, and method of planting. In some areas where environmental factors and seedling quality appear favorable for survival, planting failures still occur.

Stewart and Beebe[1/] describe an example of low seedling survival in seemingly favorable circumstances in the Entiat Valley, Washington. Herbicides were being screened for use in reducing suspected plant competition with ponderosa pine (*Pinus ponderosa* Laws.) seedlings following erosion control seeding in a wildfire burn. Survival of ponderosa pine seedlings on a northerly aspect after 2 years without herbicide treatment on the residual soil was 3 percent. Where herbicides were used to control competing vegetation, the highest survival was 21 percent. Why did the rest die? They suggested that rodents could have accounted for up to 12 percent of the loss during the first winter but had no other explanation for the low survival. Soil physical properties (table 1) do not appear restrictive. Considerable mass soil movement in the area suggests high soil moisture levels during the early growing

Table 1.--*Soil physical properties, Entiat Valley, Washington*

Depth (cm)	Organic matter	Sand	Silt	Clay	Soil moisture	
					0.1 bar	15 bars
	- - - - Percent - - - - -				Percent (weight)	
15	1.45	35.4	54.5	10.1	36.2	6.5
30	.99	37.3	51.7	11.0	33.9	8.2
60	.63	35.7	53.3	11.0	26.3	6.5

season. Willow (*Salix* spp.) is one of the predominant shrubs, again suggesting that the site is mesic in character. Orchardgrass (*Dactylis glomerata*) planted in the area for erosion control was vigorous and suggests adequate plant nutrients for seedling survival.

One possible explanation for poor conifer seedling survival and growth is an unfavorable soil biotic condition. Soils of deciduous fruit orchards develop a condition sometimes known as "the replant problem, specific replant disease or bodenmiidigkeit."[2/] A simple rest for a few years does not seem adequate, but a preplant soil treatment with a general biocide alleviates the

[1/] R. E. Stewart and T. Beebe. Survival of ponderosa pine seedlings following control of competing grasses. Proceedings of the Western Society of Weed Science 27:55-58. 1974.

[2/] B. M. Savory. Specific replant diseases causing root necrosis and growth depression in perennial fruit and plantation crops. Research Review No. 1, Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent. 1966.

condition. The exact cause of this "disease" has not been determined. Benson *et al.*[3] have investigated poor growth of apple trees replanted in old apple orchard soils of central Washington. They have found a good survival and growth response to preplant soil treatment with chloropicrin or methyl bromide. Benson and Covey[4] also tested the survival and growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings in potted orchard soils in the greenhouse. Although statistical analyses showed no difference because of the high variability, seedlings in 4 of the 20 different orchard soils showed a 200-percent or greater growth increase as a consequence of soil fumigation with methyl bromide.

Comparing the observations of Benson *et al.* and the low seedling survival of Stewart and Beebe, we decided to test the possibility that some biological factor was involved. In 1974 we conducted our study adjacent to the residual soil plots used by Stewart and Beebe. Our objective was to determine the effect of soil fumigation with methyl bromide on ponderosa pine and Douglas-fir seedling survival.

METHODS

The study area was located near the 720-m elevation in the Mad River drainage of the Entiat Valley, north-central Washington. This area with a northern aspect receives about 46 to 60 cm of annual precipitation, mostly in the winter months. The local area was severely burned by wildfire in 1970 and had been selectively logged at some earlier date. Predominant prefire overstory vegetation was ponderosa pine and Douglas-fir. Understory was redstem ceanothus (*Ceanothus sanquineus*), willow, pinegrass (*Calamagrostis rubescens*), and lupine (*Lupinus laxiflorus*). The area received a postfire rehabilitation planting treatment; and the area is presently well vegetated with orchardgrass, pinegrass, redstem ceanothus, willow, and lupine.

A randomized experimental design was used in four blocks. Each block contained 10 replications. Treatment and nontreatment sites (plots) in each block were separated by 6 m. Two blocks were located on a lower slump bench and the other two blocks on another slump bench about 65 m higher in elevation.

On April 22, 1974, each plot was covered with a 1.2-m^2 sheet of black plastic. All sides of the plastic sheet were sealed with soil. On May 1 the designated plots were fumigated; 0.45 kg of methyl bromide with 2-percent chloropicrin was released at approximately the 60-cm depth beneath the plastic on the treated plots with a metal tube injector. All plots remained covered until May 20. On this date one ponderosa pine and one Douglas-fir were planted at each plot approximately 0.5 m apart. Seedlings used were 2-0 stock, with ponderosa pine from the U.S. Forest Service Nursery, Bend, Oregon, and the Douglas-fir from the U.S. Forest Service Wind River Nursery, Carson, Washington. These trees were part of the replanting stock from the appropriate seed source being used by the Entiat Ranger District on the same area. Total trees planted

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[3] N. R. Benson, R. P. Covey, Jr., and W. A. Haglund. Soil fumigation helps replants in old apple orchards. Proceedings of Sixty-Ninth Annual Meeting, Washington State Horticulture Association, Wenatchee, Wash. 1973.

[4] N. R. Benson, and R. P. Covey, Jr. Unpublished records on file, Washington State University, Tree Fruit Research Center, Wenatchee, Wash.

were 80 ponderosa pines and 80 Douglas-firs, with half of each planted on the fumigated plots. Soil moisture at planting time was 0.15 bar, approximately field capacity for this soil type.

Seedling survival, height, and vigor were measured on November 6, 1974, on all blocks. Vigor ratings on each seedling were scored as: 1--weak, 2--average, 3--good, and 4--excellent.

RESULTS AND DISCUSSION

Observations on July 5 and August 9 showed striking leader growth on the fumigated plots for both pine and fir. This growth response was not observed on the control trees. Three Douglas-fir trees were obviously killed by the residual fumigant. Soil moisture as measured by tensiometers on the lower plots at 15 cm next to the seedlings was 0.28 bar on July 5 and 0.55 bar on August 9. At 45 cm, it was 0.24 and 0.44 bar. During early September soil moisture exceeded 0.8 bar at both depths.

Survival of ponderosa pine on the untreated plots was 92.5 percent (table 2) and on the fumigated plots 97.5 percent, not significantly different ($p = 0.05$). However, the vigor rating for the fumigated plots was nearly twice

Table 2.--*Survival and vigor rating of ponderosa pine and Douglas-fir planted in untreated forest soil and soil fumigated with methyl bromide*

Treatment	Survival	Vigor rating[1/]
	Percent	
Ponderosa pine:		
Control	92.5	[2/]1.78
Fumigated	97.5	[2/]3.21
Douglas-fir:		
Control	[3/]45.0	[4/]1.94
Fumigated	[3/]91.9	[4/]2.91

[1/] 1 = weak, 2 = average, 3 = good, 4 = excellent.

[2/] Difference significant at 5-percent level.

[3/] Difference significant at 1-percent level.

[4/] Because of high variability due to poor survival of control, this value is statistically non-significant.

that of the untreated plots, 3.21 compared with 1.78, which was statistically significant at the 5-percent level.

Douglas-fir seedling survival on the untreated plots was 45 percent and on the fumigated plots 91.9 percent, a highly significant difference ($p = 0.01$). The Douglas-fir vigor rating for the untreated plots was 1.94, compared with

2.91 for the fumigated plots. This difference was not significant at the 5-percent level--most likely due to the influence of high mortality on the untreated Douglas-fir.

Over all plantings, ponderosa pine had the highest survival in the upper two blocks (100 percent versus 90 percent) and Douglas-fir the lowest (59 percent versus 77.5 percent). Height was not measured at planting time, so first-year total growth is unknown.

It appears that we have modified some soil biotic factor(s) which may be restricting seedling development such as the presence of some organism(s) that becomes directly pathogenic to the newly transplanted conifer seedling. Other possibilities include a severe reduction in resident organisms that could release nutrients that otherwise would be biologically bound, although this could hardly account for poor seedling survival. Microbial population reduction and, especially, altering the population composition could reduce competition and antagonism against the mycorrhizal fungi on the roots of the planting stock. This could easily account for the lower vigor on the control trees and could also account for poor survival if some nutrient, for example, zinc or copper, were severely limiting. To account for this difference in behavior of the Douglas-fir and ponderosa pine, we must suggest that the pine was more tolerant to the factor(s) controlled. If moisture stress occurred, then this biotic factor could be involved in the survival differences of the two species because of the physiological nature of water use by the Douglas-fir,[5/] but stress did not appear to occur until late summer. By this time, some fir seedlings already appeared to have died. The observation of increased vigor following fumigation in the presence of adequate moisture is similar to the response noted in deciduous fruit trees where soil moisture stress is not allowed to develop. Poor survival of transplanted fruit trees has also been noted but has been attributed to arsenic. However, poor survival does not occur following fumigation.

We are not presently suggesting the use of methyl bromide or any other chemical or biotic treatment to enhance seedling survival and growth. We have shown that seedlings did not perform according to their potential on our experimental site and the cause may be biologic in nature. Further studies on the reason for the positive response to fumigation would appear to be warranted. Such studies could provide recommendations for planting forest sites with a history of low replant survival.

[5/] W. Lopushinsky and G. O. Klock. Transpiration of conifer seedlings in relation to soil water potential. Forest Science 20(2): 181-186. 1974.

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· USDA FOREST SERVICE RESEARCH NOTE

A 13.79: PNW-252

PNW-252 August 1975

FIELD AND LABORATORY TECHNIQUES FOR EVALUATING HEMLOCK SAWFLY INFESTATIONS

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by

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and

Torolf R. Torgersen, *Research Entomologist*

ABSTRACT

The hemlock sawfly, Neodiprion tsugae, *causes much defoliation of western hemlock in localized areas in southeastern Alaska. As the intensity of forest resource management increases, there will be increasing demands placed on forest pest management specialists to assess the course of infestations. This is already apparent in high value stands such as in recreation areas, near population centers, and in high-risk, overmature stands. This paper discusses techniques that will permit pest management personnel to determine trends in sawfly populations which could influence resource management decisions. Procedures for sampling and handling all stages of the sawfly and methods for determining population parameters such as larval instar composition, survival, sex ratio, fecundity, and classes of mortality are presented. Figures, descriptions, and a key are given to help the user diagnose and identify specific sources of mortality.*

Keywords: *Hemlock sawfly,* Neodiprion tsugae, *insect damage (-forest, population sampling (-forest protection.*

OREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

The hemlock sawfly, *Neodiprion tsugae* Midd. (fig. 1), is a major defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg. It feeds on previous year needles, and current year needles are avoided. Often, needles are only partially consumed, with needle stubs and midribs remaining. Larvae feed in colonies (fig. 2) and when mature spin tan, capsule-shaped cocoons (fig. 3) on host or understory vegetation.

Heavily defoliated stands (fig. 4) usually recover in a few years, but a few of the most severely defoliated trees die and some additional trees are top-killed (table 1). Radial growth

Figure 2.--Feeding colony of early instar hemlock sawfly larvae. Note character of needles which have been fed upon.

Figure 1.--Adult female hemlock sawfly on foliage of western hemlock.

Figure 3.--Hemlock sawfly cocoon showing the evenly cut margin of cap resulting from normal sawfly emergence.

Figure 4.--Severe defoliation of mature western hemlock caused by hemlock sawfly.

Table 1.--*Western hemlock damage and recovery from 2 years of heavy sawfly defoliation on three 1/5-acre plots near Todd, Alaska*

Degree of defoliation, September 1967[1]	Mean d.b.h.	Total	Condition of trees, August 1970			
			Apparently healthy	Thin crown	Top kill	Dead
	Inches		Number of trees			
None to light	16.2	16	15	0	1	0
Moderate	19.1	18	16	0	2	0
Heavy	21.8	26	15	3	8	0
Severe	16.5	7	0	3	2	2
Total	19.2	67(100%)	46(69%)	6(9%)	13(19%)	2(3%)

[1]Year that sawfly outbreak collapsed.

in most defoliated trees is temporarily reduced (fig. 5).

Most sawfly infestations in southeast Alaska occur south of Frederick Sound. Major population regulators are a larval fungus disease, most common during wetter-than-average summers, and three parasite species, most abundant during drier-than-average summers. Between 1952 and 1974 most declining sawfly population trends south of Frederick Sound occurred after two consecutive wetter-than-average summers (fig. 6). Unusually cold summer and fall weather delays larval development and inhibits oviposition.

This paper provides field and laboratory techniques required for pest management entomologists to determine whether a sawfly population is likely to increase or decrease. No recommendations are given for suppression because no pesticides have been field-tested against the sawfly, and materials and techniques will change over time.

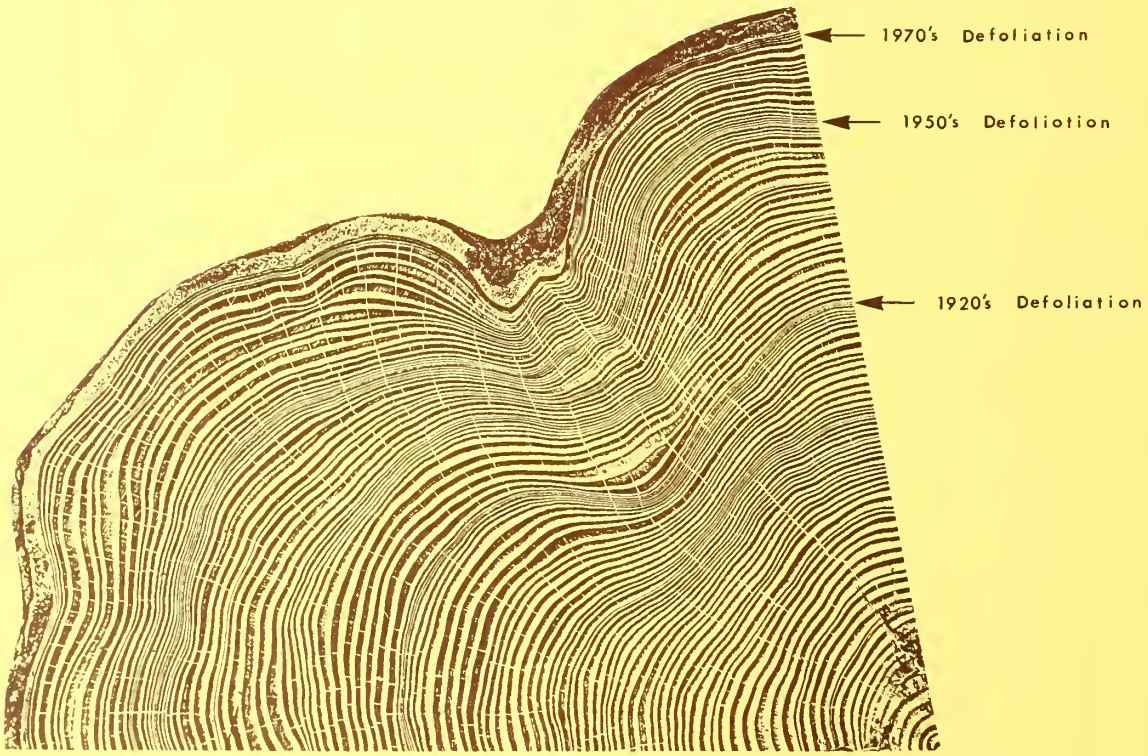


Figure 5.--Western hemlock stem section showing reduced ring widths as a result of defoliation.

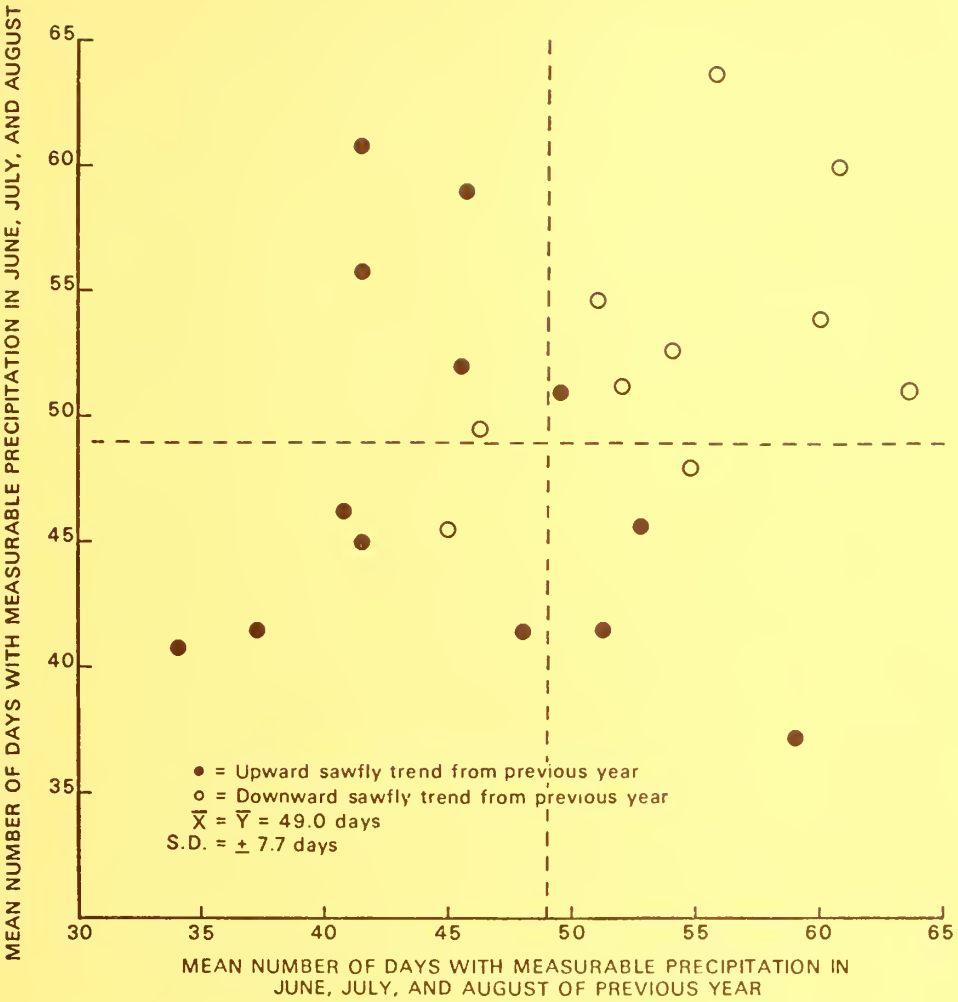


Figure 6.--Hemlock sawfly population trends south of Frederick Sound relative to frequency of precipitation during the larval periods of paired consecutive years, 1951-74 (Hard, in press).

LARVAL SAMPLING

A simple technique for collecting large numbers of larvae is to place a drop cloth beneath infested hemlock foliage and strike the branches sharply with a pole. Using a moistened camel's hair paint brush for young larvae and forceps for older larvae the dislodged larvae are then transferred from the drop cloth to vials containing 75-percent ETOH or KAAD.[1]

[1]A mixture composed of 1 part kerosene, 10 parts 95-percent ethyl alcohol (ETOH), 2 parts glacial acetic acid, and 1 part dioxane.

Larval instar composition of a collection can be determined by measuring individual head capsule widths using a dissecting stereomicroscope fitted with an ocular micrometer. Larval head capsule widths are compared against a standard (fig. 7), and percentages of larvae in the various instars are computed. Most male larvae have four feeding instars, and most female larvae have five. Head capsule widths of prepupal instars are not significantly different from widths of the last feeding instar.

It is often important to know the sex ratios of a series of larval collections from an infestation in order to determine whether change has occurred as a result of sex-differentiated mortality. Sex of individual larvae can be determined in several ways, especially in the later instars. One technique, which can also be used to determine the sex of live larvae, is to examine the underside of the larval abdomen (fig. 8) under a dissecting microscope. Ovipositor bud plates and associated structures occur only on females.

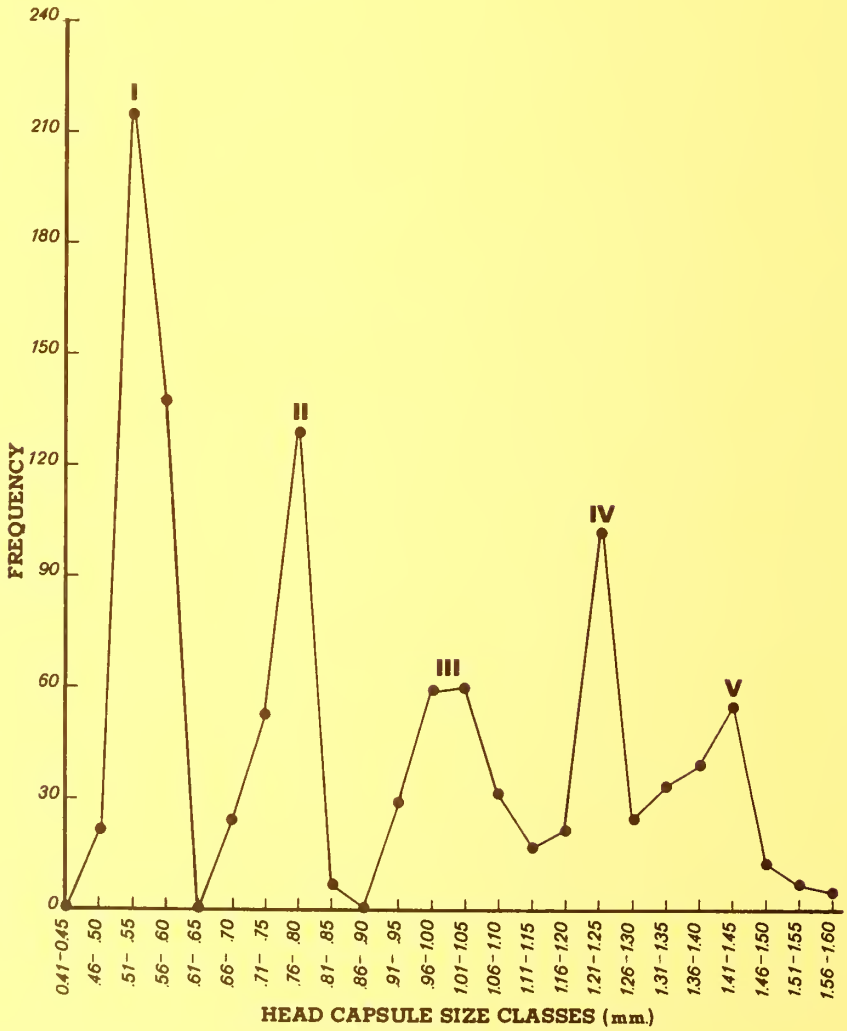


Figure 7.--Hemlock sawfly larval head capsule widths (Hard and Schmiege 1968).

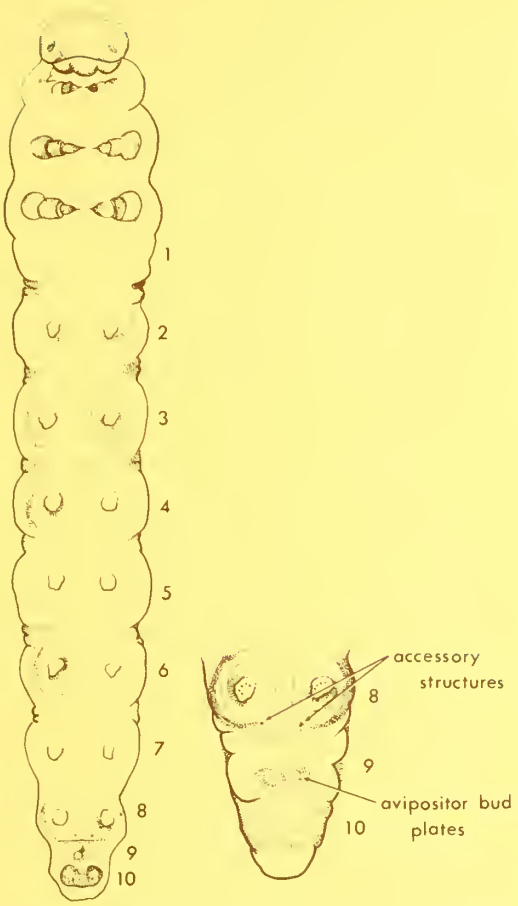


Figure 8.--Ventral view of hemlock sawfly larva and enlarged view of terminal segments showing position of ovipositor bud plates and accessory structures.

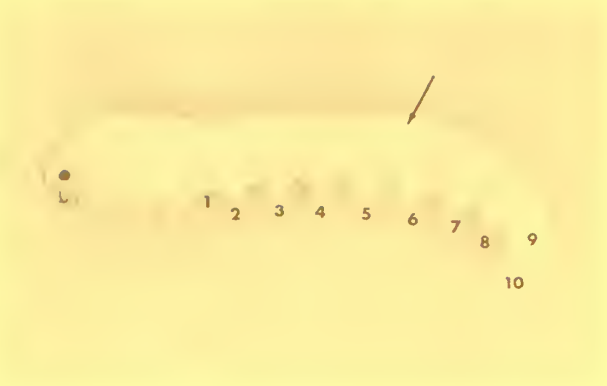


Figure 9.--Side view of prepupal sawfly larva showing position of gonad.

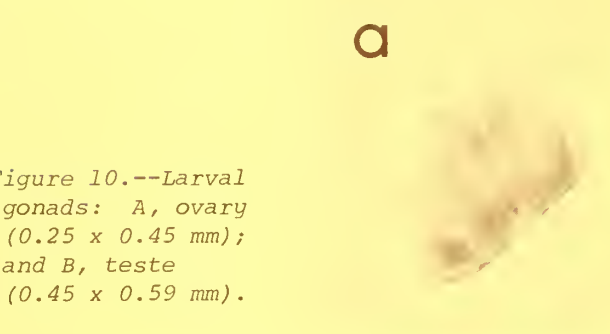


Figure 10.--Larval gonads: A, ovary (0.25 x 0.45 mm); and B, teste (0.45 x 0.59 mm).

Another technique is removing and examining the gonads, which are located internally between the fifth and sixth abdominal segments. Gonads of both sexes are more opaquely white and less translucent than the surrounding fat body (fig. 9). Ovaries resemble bunches of bananas (fig. 10A); testes resemble cauliflowers (fig. 10B) and are usually larger than ovaries.

The major biotic mortality factor of sawfly larvae in Alaska is a fungus, *Entomophthora sphaerosperma* Fres. Recently killed larvae are brown and rigid but are soon covered with a

light brown, velvety fungal mat (fig. 11). The disease usually becomes most apparent in late larval populations in early to middle August when most larvae are in the last feeding or prepupal instars. Head capsule widths of preserved larvae killed by the fungus can be measured in the laboratory to determine approximate sex ratio by comparing individual widths with figure 7. Those widths that fall in the fifth instar represent females.

Figure 11.--Hemlock sawfly larva killed by Entomophthora sphaerosperma.

COCOON SAMPLING

During the years 1969 through 1973 in the southern Panhandle, cocoon formation began in the second or third week in August. Field studies showed that by mid-October at least 40 percent of the current year's cocoons had fallen from the foliage and twigs where they were formed. By mid-November more than 65 percent of the opened and unopened cocoons had been lost. Therefore, in order to obtain the best sample of cocoons to determine incidence of mortality factors and other population parameters such as sex ratio and fecundity, it is important to sample about the last week in September. Collecting during this period will insure that parasites have had adequate time to exploit the cocoon population and that few sawflies, if any, have emerged.

Often some cocoons from previous generations will still be on the host trees and understory vegetation. They can almost always be separated from new cocoons, because cocoons that have weathered a year or more are a darker brown than cocoons of the current generation, which are a light tan.

The best estimates of population parameters such as percent sawfly emergence, adult sex ratio, mean fecundity, percent parasitized, and percent fungus-killed sawflies can be determined by sampling the entire crowns of trees within the stand. However, this requires that sample trees be felled. Our experience has shown that reasonably good estimates of population parameters can be determined by sampling the lower crowns of fringe trees along the beach without felling sample trees. Cocoons are handpicked from host branches and placed in perforated or screen-bottomed plastic vials. In order to evaluate cocoon population densities, the amount of time in hours and minutes actually spent removing cocoons from foliage should be recorded. This enables computation of cocoons collected per man hour, a rough index of cocoon population density. It is important to remember, however, that cocoon population levels are not necessarily closely related to larval population levels, because fungus disease often decimates high larval populations before many cocoons are spun.

Unopened cocoons should be placed individually in gelatin capsules[2] to

[2]No. 00 (9 x 25 mm) gelatin capsules are manufactured by Eli Lilly Company, Indianapolis, Indiana. Mention of any product or company does not constitute endorsement or approval by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

keep each sawfly or parasite with its cocoon; and incubated at 12° to 19° C (55° to 66° F) and 80- to 90-percent relative humidity. Cocoons to be held for delayed emergence must be incubated at temperatures above freezing but below 5.5° C (42° F), because sawflies can complete development and emerge at the warmer temperature.

Sawfly and parasite adults begin to emerge from the cocoons after several weeks of incubation. Emerging insects can be easily differentiated because sawflies are "thick waisted" and have serrated or plumed antennae (fig. 12A, B), whereas parasites are "thread waisted" and usually have long threadlike antennae (fig. 13A, B, C). Normally, male sawflies begin to emerge several days earlier than the females. Sawfly sexes are separated on the basis of antennal shape--plumed in the male (fig. 12B) and serrated in the female (fig. 12A).

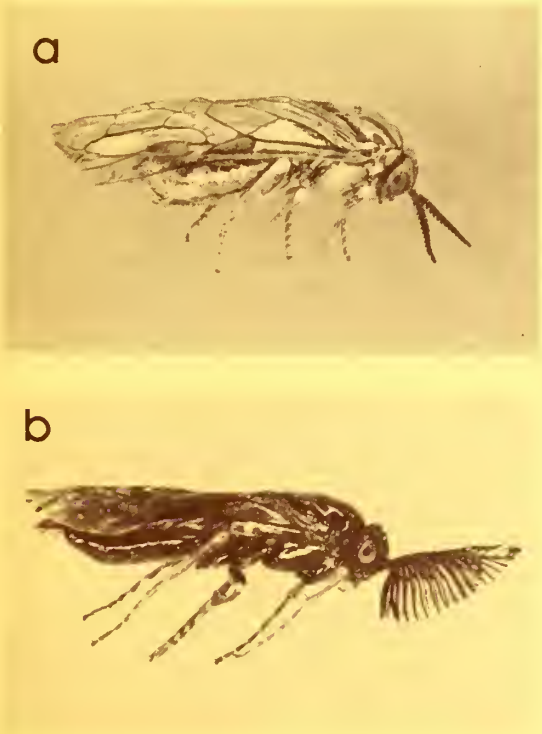


Figure 12.--Side views of adult hemlock sawflies showing: A, serrated antennae and light body color of female, and B, plumed antennae and dark body color of the male.

Figure 13.--Side views of adult females of: A, Delomerista japonica diprionis*; B,* Oresbius tsugae tsugae*; C,* Itoplectis quadricingulatus*; parasites that oviposit and emerge from cocoons of the hemlock sawfly.*

There are nearly 20 species of insects in about a dozen genera that parasitize the larva or cocooned prepupa of the sawfly. All the important sawfly parasites kill the host and overwinter within the host cocoon; parasite field emergence occurs in early summer the following year. Emerging parasites chew a jagged hole at or near the end of the cocoon (fig. 14A, B). Normally, only a single parasite emerges, but sometimes as many as a dozen tiny wasps emerge from one cocoon.

Overwintering for parasites is facultative so that parasitized cocoons collected in late September produce adults after several weeks of incubation at a temperature of 18° to 20° C (65° to 68° F).

Figure 14.--Hemlock sawfly cocoons showing parasite emergence holes of: A, Amblymerus verditer; *and B,* Oresbius tsugae tsugae. *The latter is also characteristic of* Delomerista japonica diprionis *and* Itoplectis quadricingulatus.

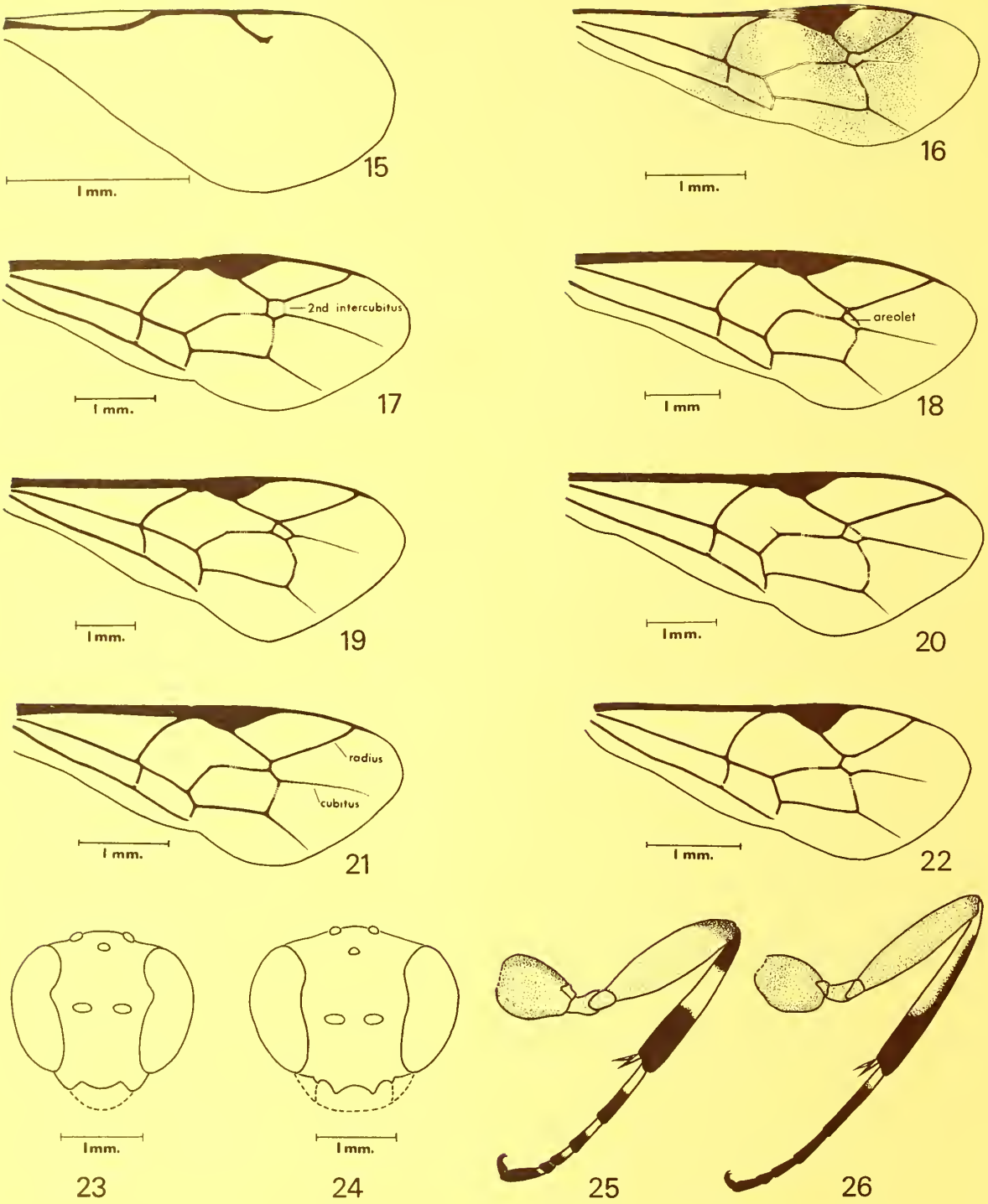
The most commonly reared parasites are *Delomerista japonica diprionis* Cush., *Oresbius (= Opidnus) tsugae tsugae* (Cush.), and *Itoplectis quadricingulatus* (Prov.), which in combination with the rarer parasites in the complex, have accounted for up to 54-percent mortality in the cocoon population. The following key simplifies identification of the major adult parasite species.[3]

[3]For a more complete treatment of sawfly parasite biology and identification, see Torgersen (1968).

Key to Some Parasites of *Neodiprion tsugae*

1. Wings absent, female.....*Gelis* sp.
1. Wings present, males and females.....2
   2. Forewing venation reduced (fig. 15); small (less than 3 mm), mostly metallic green-bodied wasps; short elbowed antennae; commonly gregarious.....*Amblymerus verditer*
   2. Forewing venation well developed (figs. 16-22); body 5 mm or longer; antennae long and threadlike (fig. 13A, B, C).....3
3. Forewings with dark bands (fig. 16); body and legs reddish brown with darker areas on thorax and abdomen.....*Gelis tenellus*
3. Forewings without dark bands (figs. 17-22).....4
   4. Areolet present (figs. 17-20).....5
   4. Areolet absent (figs. 21, 22).....8
5. Areolet five-sided; second intercubitus (fig. 17) sometimes faded; females with narrow light band along inner margin of compound eye; males with white face; female as in fig. 13B.....*Oresbius tsugae tsugae*
5. Areolet three- or four-sided (figs. 18-20).....6
   6. Areolet three-sided (fig. 18); first tarsal segment of hind leg about half as long as tibia; ovipositor very short, barely reaching beyond end of abdomen; face, clypeus, antennal base anteriorly and/or mandibles commonly patterned with yellow; lower portion of thorax sometimes yellow.....*Lamachus* spp.
   6. Areolet four-sided (figs. 19, 20); first tarsal segment of hind leg less than half as long as tibia; ovipositor about as long as hind tibia.....7
7. Inner margin of compound eye markedly concave opposite antennal base (fig. 23); hind tibia of both sexes black, with an encircling white band near basal one-third (figs. 13C, 25); wing venation as in fig. 19; face of both sexes black.....*Itoplectis quadricingulatus*
7. Inner margin of compound eye not markedly concave opposite antennal base (fig. 24); hind tibia without encircling white band, usually white along ventral margin and/or basally (figs. 13A, 26); face of male white, face of female black; wing venation as in fig. 20....*Delomerista japonica diprionis*
   8. Radius and cubitus divergent (fig. 21); ovipositor short, barely reaching beyond end of abdomen.....*Lamachus* spp.
   8. Radius and cubitus slightly convergent, then divergent (fig. 22); ovipositor long, about as long as hind tibia.....*Mastrus* spp.[4]

[4]Males of some uncommon *Gelis* species will also key out here.



Figures 15-26.--15-22, forewings: 15, Amblymerus verditer; *16,* Gelis tenellus; *17,* Oresbius tsugae tsugae; *18,* Lamachus *sp.; 19,* Itoplectis quadricingulatus; *20,* Delomerista japonica diprionis; *21,* Lamachus *sp.; 22,* Mastrus *sp. 23, 24, anterior view of heads: 23,* Itoplectis quadricingulatus; *24,* Delomerista japonica diprionis. *25, 26, hind legs: 25,* Itoplectis quadricingulatus; *26,* Delomerista japonica diprionis.

When sawfly and parasite emergence has ceased, remaining cocoons should be dissected and their contents analyzed. Contents of dissected cocoons will fall within categories such as the following: unemerged sawfly or parasite adult, sawfly or parasite pupa, prepupal sawfly larva in extended diapause, parasite larva, and *Entomophthora*-killed sawfly larva. Most categories are readily determined through ocular examination, but determination of the presence of *Entomophthora* or of a parasite larva requires special procedures. Usually, the *Entomophthora*-killed host consists of a dried, mummified, barely recognizable larva within the cocoon. A smear slide can be prepared by placing a bit of tissue in a drop of water or 10-percent potassium hydroxide (KOH) solution on a microscope slide and pressing a cover slip into place. Examination of the tissue through a compound microscope at 150X magnification verifies the presence of *Entomophthora* if the smear appears to be composed of spherical, thick-walled resting spores 25 to 30µm in diameter (fig. 27).

Living parasite larvae are legless, tapered posteriorly, and cream colored. Dead parasite larvae become shortened, dark brown, and shriveled. Verification of the species of a living or dead parasite larva is based mainly

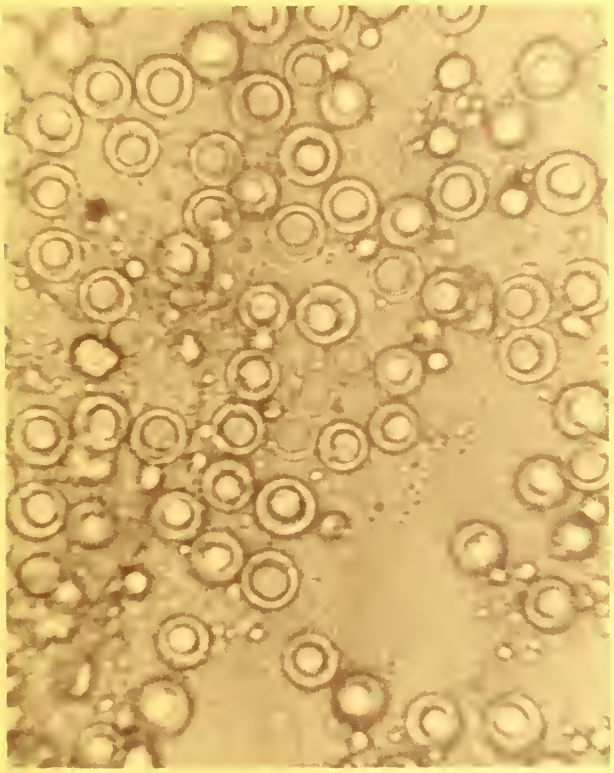


Figure 27.--Resting spores (270X) of Entomophthora sphaerosperma.

on the appearance of the sclerotic structures associated with the mouthparts. These structures (fig. 28A, B, C)[5] are apparent from the front on both living and dead larvae. Soaking the dead parasite larva in a 10-percent solution of KOH for an hour or more until the carcass is softened makes the larval skin easier to manipulate.

[5]For a more complete treatment of identifications of the larval stage of sawfly parasites, see Torgersen (1969).

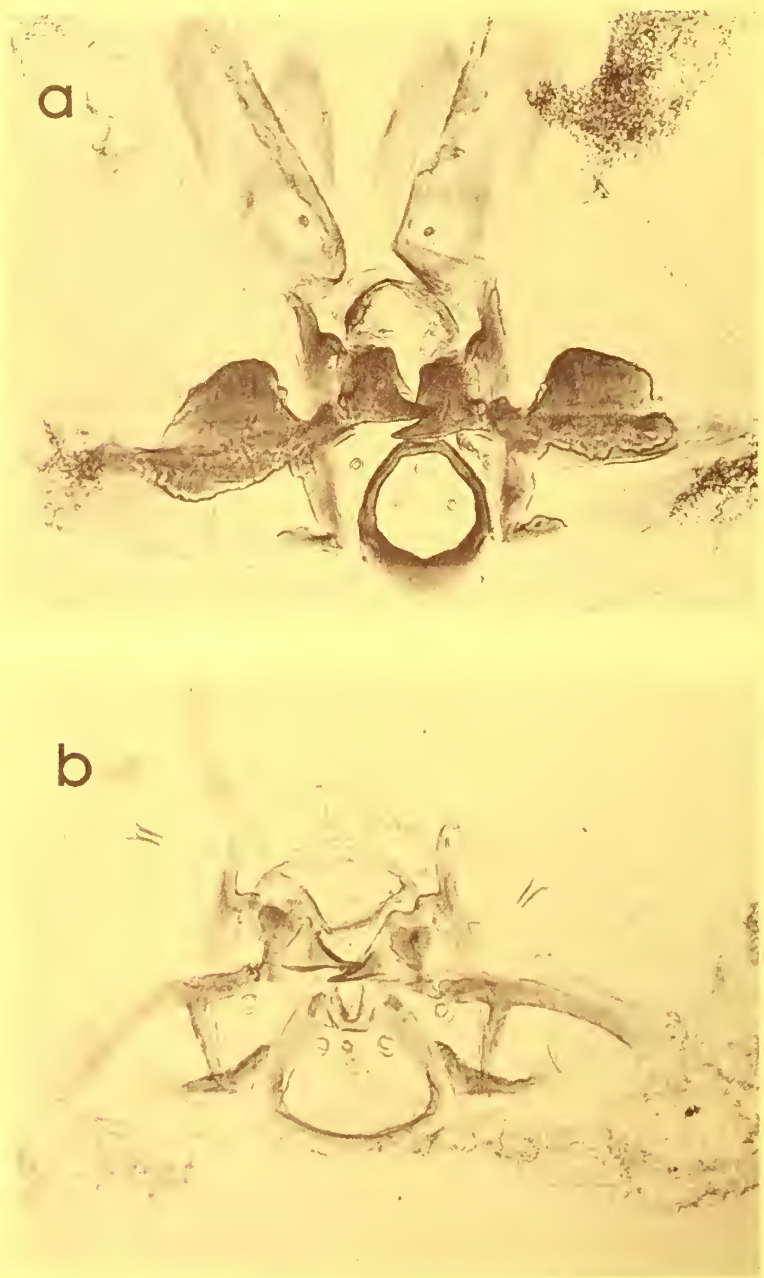


Figure 28.--Anterior views of structures associated with the larval mouthparts of: A, Delomerista japonica diprionis*; B,* Oresbius tsugae tsugae.

Figure 28.--Anterior views of structures associated with the larval mouthparts of (continued): C, Itoplectis quadricingulatus.

Determination of the parasite responsible for death of the cocooned sawfly is possible even if the host cocoon is separated from the parasite which emerged from it, or if opened cocoons are collected following field emergence of the parasites. Since fewer than 10 percent of cocoons remain on foliage or twigs beyond June of the season following their formation, most cocoons, whether opened or not, will be found on the ground. The presence of an emergence hole (fig. 14A, B) verifies parasitization, and dissection will reveal the nearly white, shriveled, shed larval skin with the characteristic mouthparts. An hour's soaking in KOH softens the dried skin to facilitate observing the mouthparts. Preparation of a semipermanent microscope slide using a nonresinous mounting medium[6] will also simplify examining the mouthparts for making a determination.

Diameter of all cocoons should be measured using a dissecting microscope fitted with a calibrated ocular micrometer disk. Measurements can be made when unopened cocoons are being dissected. The microscope, its magnification, and the precise conversion ratio of ocular micrometer units to millimeters used for measuring the cocoons should also be recorded. For accurate measurements, the microscope

[6]Turtox CMC-10 can be used for this purpose. Available through General Biological Supply House, Inc., 8200 South Hoyne Ave., Chicago, Illinois 60620.

calibration should be rechecked before each use. Cocoon diameter measurements are useful because they provide a means to determine sex of cocoons that did not produce adult sawflies. This is done by plotting frequency distribution of cocoon diameters grouped according to arbitrary size classes of about 0.15 to 0.20 mm. Male cocoons are smaller than female cocoons, and overlap is minimal (fig. 29). Sometimes female cocoon diameters have a bimodal frequency distribution; but there is not as sharp a dip between the modes as there is between male and female cocoon diameters, which occurs between 2.6 and 3.0 mm. Cocoon size varies among sample areas and years; therefore samples from separate areas must be plotted separately to determine the separation point between male and female cocoons as accurately as possible.

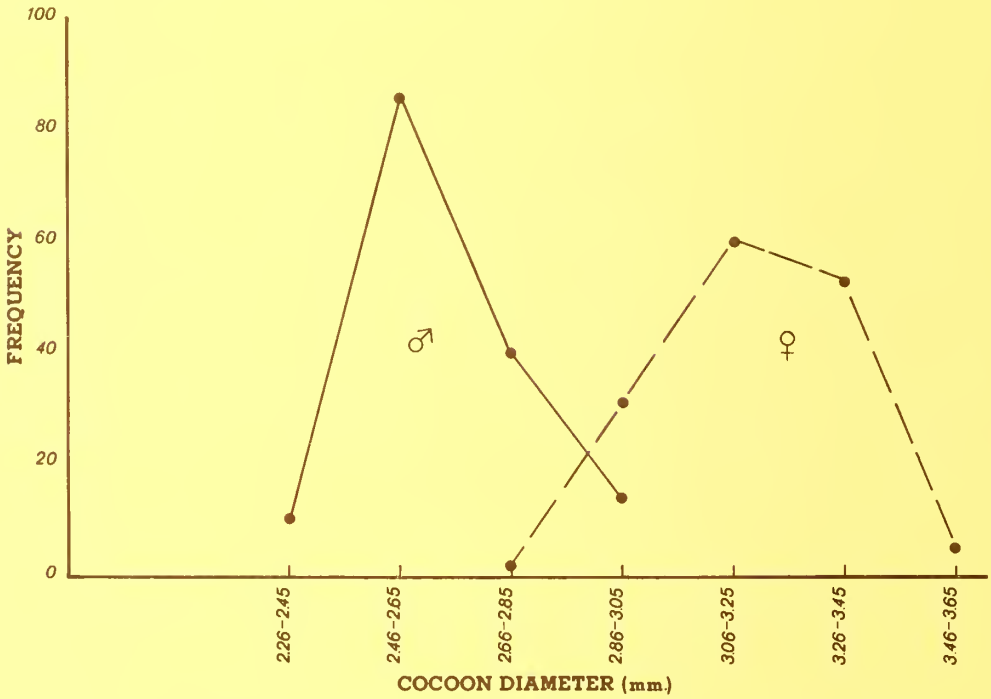


Figure 29.--Hemlock sawfly cocoon diameters (Hard and Schmiege 1968).

The separation of sexes can be hastened by sorting cocoons using slotted seed dockage sieves[7] (fig. 30). A tray with 2.98-mm x 19-mm (7.5/64- x 3/4-in) slots retains large female cocoons and passes smaller females and males. A lower tray with 2.58-mm (6.5/64-in) slots passes most male cocoons but retains intermediate diameter male and female cocoons. These must be measured and their frequency distribution plotted to determine the separation point between sexes. When the females emerge they can be either dissected immediately and eggs counted, or preserved in KAAD and dissected later to determine actual fecundity.

[7]Manufactured by Burrows Equipment Company, 1316 Sherman Avenue, Evanston, Illinois 60204--9- by 9-in perforated metal sheet type, oblong holes 6.5/64- and 7.5/64- x 3/4-in.

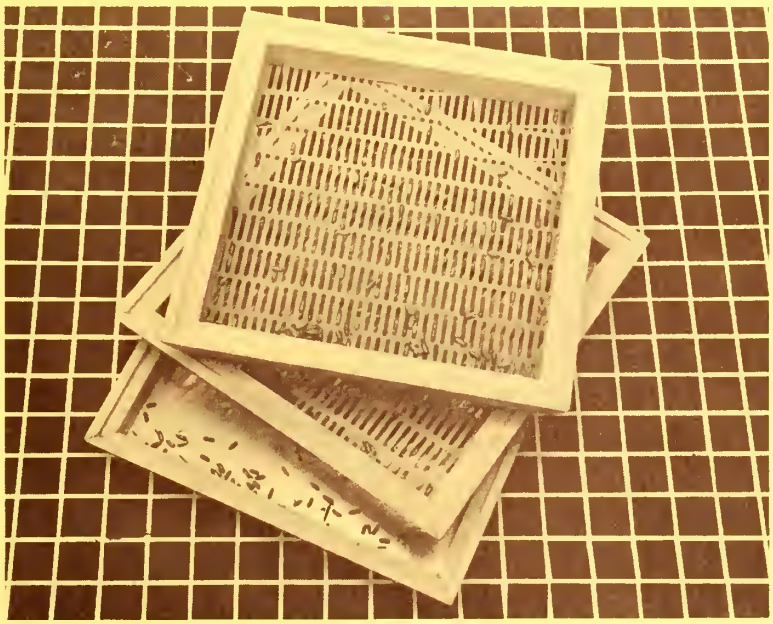


Figure 30.--Seed dockage sieves used for size-sorting hemlock sawfly cocoons.

Female cocoon diameter can be used to estimate fecundity. However, the correlation and slope of fecundity on cocoon diameter varies among places and years, so the regression in figure 31 should not be used to estimate fecundities of new samples. A double sampling procedure requires measuring cocoon diameter and fecundity of a small random sample of females to determine the regression of fecundity on cocoon diameter. Then cocoon diameters of a large number of female cocoons are measured, and the mean diameter is entered in the regression equation[8] to estimate population

[8]The formula for estimating population mean fecundity, $\bar{Y}$, is $\bar{Y} = \bar{Y}_S + b(\bar{X}_L - \bar{X}_S)$, where $\bar{Y}_S$ = mean fecundity of the small sample, b = regression coefficient of the small sample, $\bar{X}_L$ = mean cocoon diameter of the large sample, and $\bar{X}_S$ = mean cocoon diameter of the small sample.

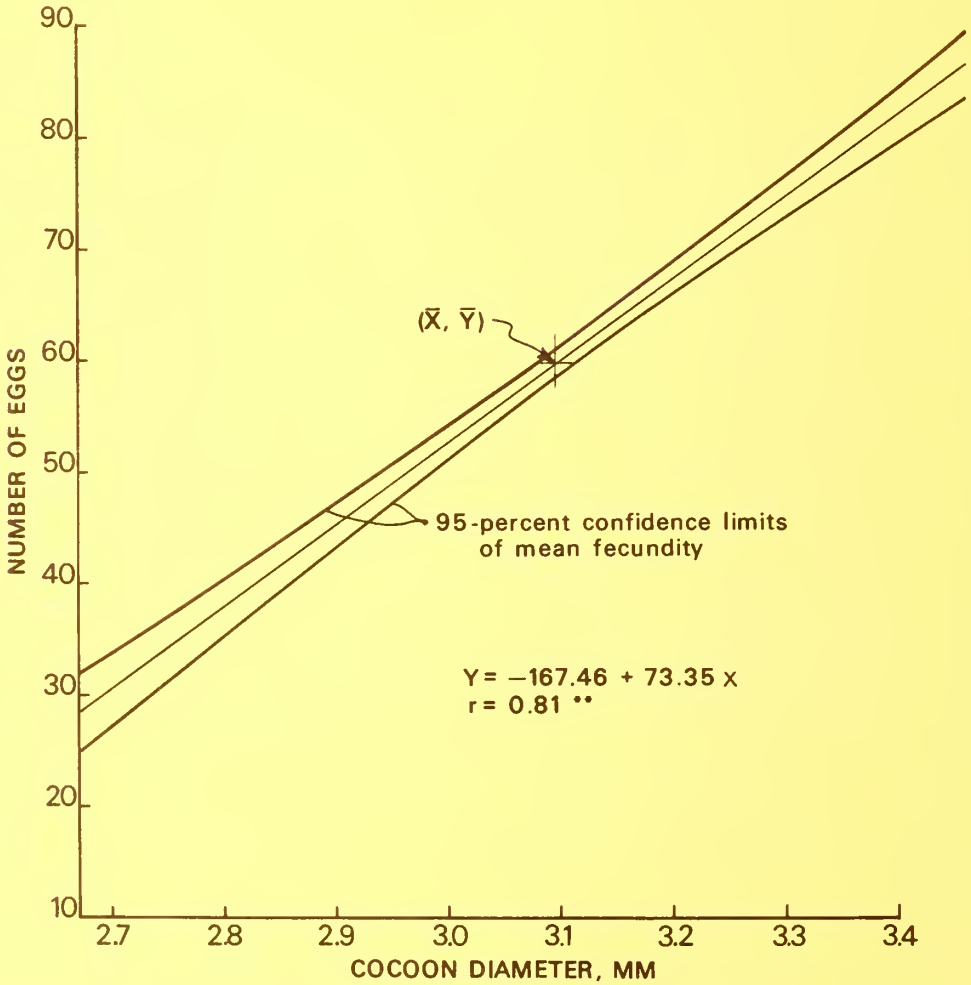


Figure 31.--Relation of hemlock sawfly fecundity to cocoon diameter, southeast Alaska, 1972.

mean fecundity. Female forewing length is also highly correlated with fecundity (fig. 32); therefore double sampling may be used to estimate mean fecundity of a sample by establishing the regression of fecundity on forewing length of a small random sample and then use the regression to estimate mean fecundity of a large sample whose mean forewing length is known. The benefit of double sampling is that cocoons and wings of many females can be measured in the time required to dissect and count the eggs in a single female, and accuracy in estimating overall population mean fecundity will likely be improved.

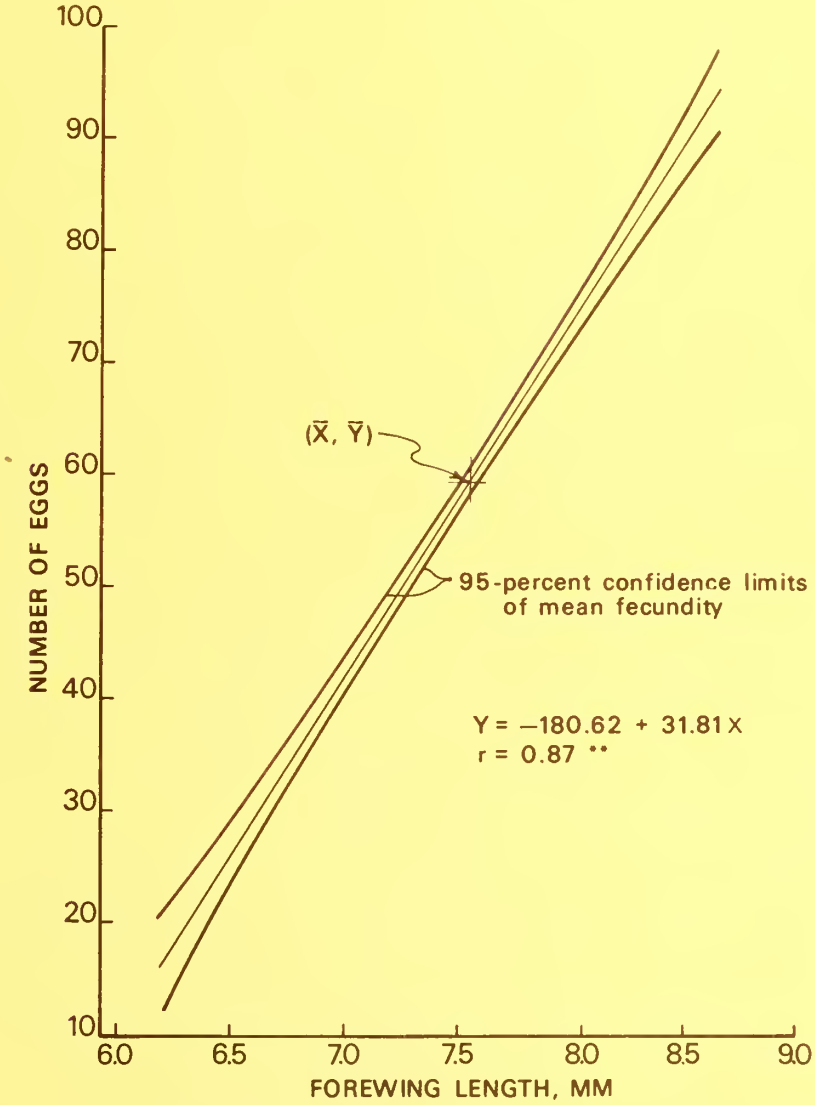


Figure 32.--Relation of hemlock sawfly fecundity to forewing length, southeast Alaska, 1972.

EGG SAMPLING

Field egg populations can be sampled after November 1, when most females have completed oviposition. During an unusually cold fall, females may have little opportunity to lay eggs. Days are short and often stormy in November, but fall egg sampling may be required to provide leadtime if control activities are anticipated for the following summer. Otherwise egg sampling can be postponed to the following March or April when days are longer.

If an infestation borders on a beach or clearing, an experienced entomologist can determine whether a high egg population is present by randomly selecting western hemlock branch tips reached from the ground and examining them for presence of egg clutches (fig. 33). The branch tips most likely to bear eggs are those that project farthest from the tree crown and are most exposed to the sun. This gives only a very rough index of egg abundance, however, and requires much empirical knowledge of the sawfly.

A better technique for assessing egg populations is through a sequential sampling plan[9] developed for this species. Intermediate crown class western hemlock trees are selected randomly. Four 18-in branch tips are removed from the midpoint of the upper crown of each sample tree and examined until an egg is found. A trace is drawn up one square on the sequential sampling form (fig. 34) for an egg-bearing tree or right one square for a tree without eggs. Trees are sampled sequentially until the trace drawn on the form crosses a decision line. The intermediate decision lines are adequate for most sampling because they can be expected to give an incorrect decision only 1 time in 10.

[9]For a more complete description of the sampling procedure, see Hard (1971b).

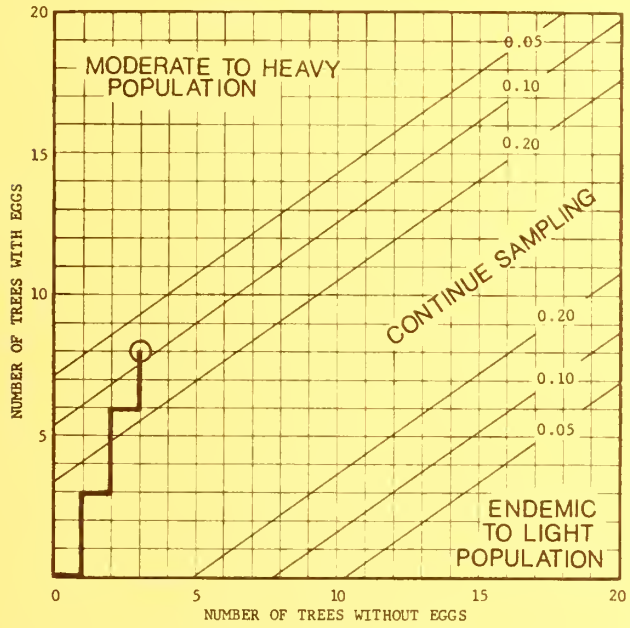
Figure 33.--Hemlock foliage showing sawfly eggs deposited in the edges of needles.

HEMLOCK SAWFLY SEQUENTIAL EGG SAMPLING FORM

Date: Nov. 10, 1969 Hard and Curtis

Location of Sampling Area: Mc Kenzie Inlet, South Tongass National Forest

Plot Location: West Side Peacock Island



TREE NO.	AZIMUTH (degrees)	DISTANCE (chains)	DBH (inches)	HEIGHT (feet)	CROWN DEFOLIATION (25% increm.)	NO. SAMPLE BR. DEFOL. (0 to 4)	EGGS PRESENT (yes or no)
1	120	3	14	—	< 25	0	No
2	60	1	16	—	50	2	Yes
3	60	4	16	—	75	4	Yes
4	180	3	18	—	> 75	4	Yes
5	120	2	22	—	25	1	No
6	360	5	12	—	50	3	Yes
7	60	6	16	—	> 50	2	Yes
8	300	6	18	—	75	4	Yes
9	300	1	24	—	> 50	0	No
10	180	5	16	—	< 50	2	Yes
11	120	4	14	—	< 50	2	Yes
12							
13							
14							
15							
16							
17							
18							
19							
20							

Figure 34.--Hemlock sawfly egg sequential sampling form (Hard 1971b).

CONCLUDING REMARKS

Use of the techniques presented in this guide will enable pest management entomologists to predict the probable trend of hemlock sawfly infestations based on the following criteria:

1. Frequency of precipitation during the previous and current summers.
2. Population vigor of the current generation determined by adult sex ratio and fecundity.
3. Assessment of the effectiveness of mortality factors such as parasites and pathogens.
4. Expected larval population the following year determined by egg sampling.

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We thank Christine Andrew for the many tedious hours spent doing laboratory work, which helped in constructing this guide. We also thank Marion Simpson for preparing some of the illustrations used here.

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REFERENCES

Brown, George Stuart
1951. Some factors influencing the populations of the hemlock sawfly, *Neodiprion tsugae* Midd. 57 p., illus. Unpubl. M.S. thesis, Univ. B.C., Vancouver.

Hard, J. S.
1971a. Effects of semistarvation during late larval stages on survival and fecundity of the hemlock sawfly in the laboratory. USDA For. Serv. Res. Note PNW-157, 8 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

_____ 1971b. Sequential sampling of hemlock sawfly eggs in southeast Alaska. USDA For. Serv. Res. Note PNW-142, 9 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

_____ and D. C. Schmiege
1968. The hemlock sawfly in southeast Alaska. USDA For. Serv. Res. Pap. PNW-65, 11 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Hard, John S.
[In press.] Natural control of hemlock sawfly, *Neodiprion tsugae* Midd. (Hymenoptera: Diprionidae) populations in southeast Alaska. Can. Entomol.

Hopping, G. R., and H. B. Leech
1936. Sawfly biologies. I. *Neodiprion tsugae* Middleton. Can. Entomol. 68(4): 71-79, illus.

Schmiege, Donald C.
1970. Hemlock sawfly. U.S. Dep. Agric. For. Pest Leafl. 31 (rev.), 4 p., illus. Washington, D.C.

Torgersen, Torolf R.
1968. Parasites of the hemlock sawfly, *Neodiprion tsugae*, in coastal Alaska. Ann. Entomol. Soc. Am. 61(5): 1155-1158, illus.

1969. Hymenopterous parasites of the hemlock sawfly, *Neodiprion tsugae* Middleton, in southeast Alaska, with a key to larval remains. J. Entomol. Soc. B.C. 66(8): 53-62, illus.

1973. New parasite-host records for North American Ichneumonidae (Hymenoptera) in Alaska. Can. Entomol. 105(7): 997-998.

Wyatt, G. R., and P. H. D. Parizeau
1946. Studies on the hemlock sawfly, *Neodiprion tsugae* Midd. at Quatsino Sound, B.C., in 1945. 8 p. Unpubl. rep., For. Insects Invest., Victoria, B.C.

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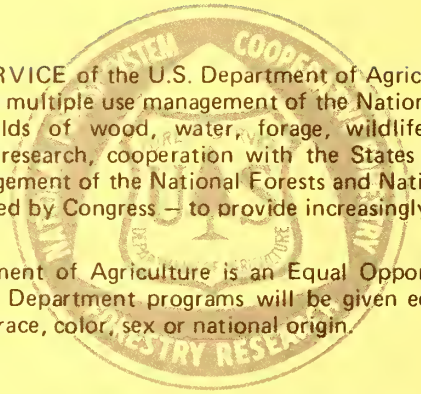

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79 PNW-253
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August 1975

COMPARATIVE TOLERANCES OF LODGEPOLE PINE AND THIN-LEAVED HUCKLEBERRY TO BORON AND MANGANESE

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Don Minore

Plant Ecologist

ABSTRACT

Lodgepole pine and thin-leaved huckleberry seedlings were treated with several levels of boron and manganese in the greenhouse. Huckleberry was less tolerant of excess boron than was lodgepole pine. Both species tolerated excess manganese. Further testing of these micronutrients to favor huckleberry and eliminate lodgepole pine is not recommended.

KEYWORDS: Lodgepole pine, thin-leaved huckleberry, micronutrients(-growth, herbicide side effects.

INTRODUCTION

Lodgepole pine (*Pinus contorta*) is one of the most important invading species in the dwindling mountain huckleberry fields of Oregon and Washington. Thin-leaved huckleberry (*Vaccinium membranaceum*) is the most important berry species. Several experiments are underway at the Pacific Northwest Forest and Range Experiment Station to determine the most efficient methods of controlling the lodgepole pine and other invaders without damaging thin-leaved huckleberry. Conventional herbicides have not been successful in thin-leaved huckleberry fields. However, several authors (Smith et al. 1947, Medappa and Dana 1970, Gambi et al. 1971) either refer to tolerances of boron and manganese in other *Vaccinium* species or report high concentrations of manganese in these species.

The study reported here was undertaken to determine the relative tolerances of lodgepole pine and thin-leaved huckleberry to several levels of boron and manganese applied in a greenhouse environment. It is a preliminary test in which I hoped to find concentrations of these micronutrients that would favor huckleberry and eliminate lodgepole pine.

METHODS

Huckleberry and lodgepole pine plants were grown from seed in a growth chamber. When they were 4 months old, they were chilled for 3 months, then grown on greenhouse benches in a peat-sand soil (50 percent peat, 50 percent sand) fertilized periodically with ammonium sulfate, a dilute macronutrient solution,[1/] and small amounts of fritted trace elements. A randomized-blocks experimental design was used, with one seedling per treatment in each block. The total height of each seedling was measured and recorded 1 month after the end of the chilling period. Micronutrient treatments then were applied to each species, in each of the four greenhouse blocks:

Control (no boron, no manganese)	B1 + M1	B3 + M1
B1 (10 p/m boron)	B1 + M2	B3 + M2
B2 (100 p/m boron)	B1 + M3	B3 + M3
B3 (500 p/m boron)	B1 + M4	B3 + M4
B4 (1,000 p/m boron)	B2 + M1	B4 + M1
M1 (20 p/m manganese)	B2 + M2	B4 + M2
M2 (200 p/m manganese)	B2 + M3	B4 + M3
M3 (1,000 p/m manganese)	B2 + M4	B4 + M4
M4 (2,000 p/m manganese)		

Borax and manganese sulfate were used to obtain the required B and Mn concentrations. For each micronutrient treatment, 50 ml of solution were applied to each seedling. Micronutrient treatments were randomly located in each block. The initial treatment with the same solution concentrations and volumes was repeated 2 weeks later.

Total heights were remeasured 4 months after the initial micronutrient treatment. All plants then were harvested, ovendried at 65° C for 48 hours, and weighed. Survival, height growth, and weight data were all subjected to analyses of variance.

[1/] 1.6 g $Ca(NO_3)_2$, 1.0 g KNO_3, 0.5 g $MgSO_4$, and 0.3 g KH_2PO_4 per liter H_2O.

RESULTS AND CONCLUSIONS

Toxicity symptoms were more severe on huckleberry than on lodgepole throughout the 4-month growth period. All huckleberries treated with both 1,000 p/m B and 0 p/m Mn died (table 1), and lower boron concentrations caused leaf mottling and spotting. However, the huckleberries treated with high concentrations of both manganese and boron seemed less affected than those treated with high concentrations of boron alone. Needle browning was common on all of the lodgepole pines, but none died, and the only treatment-associated toxicity symptom observed was blue-green foliage and shorter needles on many of the treated trees.

Table 1.--*Huckleberry survival, by nutrient treatment*

Manganese concentration (p/m)	Boron concentration (p/m)					Average survival, all boron treatments
	0	10	100	500	1,000	
				Percent		
0	100	100	100	100	0	80
20	75	100	100	50	50	75
200	75	75	100	100	75	85
1,000	100	100	100	50	75	85
2,000	75	100	100	50	100	85
Average survival, all manganese treatments	85	95	100	70	60	

The lodgepole pines were heavier than the huckleberries (table 2). Boron concentrations of more than 100 p/m significantly reduced the final weights of both huckleberry and lodgepole pine. Boron also reduced height growth of both species (table 3). Except for their interaction with boron on huckleberry survival, the manganese treatments had no statistically significant influence on either huckleberry or lodgepole pine.

Although no significant species X micronutrient interactions are evident in the weight- and height-growth information presented here, the survival data indicate that thin-leaved huckleberry is less tolerant of high boron concentrations than is lodgepole pine. Any use of large quantities of boron in the mountain huckleberry fields probably would be counterproductive--huckleberries would be killed before the invading lodgepole pines. Both species seem to be manganese-tolerant. Further testing of either micronutrient as a selective vegetation-control agent is not recommended.

Table 2.--*Average ovendry weights of huckleberry* (H) *and lodgepole pine* (LP), *by nutrient treatment*[1/]

Manganese concentration (p/m) and species		Boron concentration (p/m) and species										Average, H	Average, LP	Average, both species
		0		10		100		500		1,000				
		H	LP	H	LP	H	LP	H	LP	H	LP			
		Grams												
0	H	1.375		0.987		0.865		.0.622		0.180		0.806		
	LP		4.082		4.103		3.572		2.362		3.163		3.456	2.131
20	H	1.162		1.340		1.229		.548		.360		.928		
	LP		3.935		3.480		4.000		3.325		2.280		3.404	2.166
200	H	1.053		1.825		.470		.533		.583		.893		
	LP		3.273		4.145		3.838		2.763		3.512		3.506	2.200
1,000	H	1.070		.950		2.12⁄		.358		.715		1.043		
	LP		2.728		4.083		3.233		3.985		2.815		3.369	2.206
2,000	H	.923		1.586		1.696		.342		.596		1.029		
	LP		4.355		4.172		4.678		2.565		2.928		3.740	2.384
Average, H		1.117		1.338		1.277		.481		.487		.940		
Average, LP			3.675		3.997		3.864		3.000		2.940		3.495	
Average, both species		2.396		2.667		2.570		1.740		1.713				

[1/] Species differences and the differences among boron treatments are statistically significant at the 0.01 level. The differences among manganese treatments are not statistically significant, and there are no significant interactions.

Table 3.--*Average height growth of huckleberry* (H) *and lodgepole pine* (LP), *by nutrient treatment*[1/]

Manganese concentration (p/m) and species		Boron concentration (p/m) and species										Average, H	Average, LP	Average, both species
		0		10		100		500		1,000				
		H	LP	H	LP	H	LP	H	LP	H	LP			
		Centimeters												
0	H	4.52		0.12		2.72		0.12		0		1.50		
	LP		3.02		1.88		1.58		1.92		0.65		1.81	1.65
20	H	1.02		2.15		.70		.42		.02		.86		
	LP		1.60		2.55		1.75		1.42		.88		1.64	1.25
200	H	1.92		4.88		1.05		1.60		.02		1.89		
	LP		1.98		2.95		1.60		2.20		3.12		2.37	2.13
1,000	H	3.12		2.95		6.95		.05		0		2.61		
	LP		2.78		1.60		2.15		3.25		1.95		2.35	2.48
2,000	H	0		4.40		.70		0		.02		1.02		
	LP		1.08		1.92		2.92		1.88		2.12		1.98	1.50
Average, H		2.12		2.90		2.42		.44		.01		1.58		
Average, LP			2.09		2.18		2.00		2.13		1.74		2.03	
Average, both species		2.10		2.54		2.21		1.29		.88				

[1/] Differences among boron treatments are significant at the 0.05 level. Manganese differences, species differences, and the manganese x boron interaction are all nonsignificant.

LITERATURE CITED

Gambi, Ornella Vergnano, R. Gabbrielli, L. Letti, and V. Polidori
1971. Aspetti biogeo chimici del manganese nell' Apennino Tosco-Emiliano. (Biogeochemical aspects of manganese in the Tuscan-Emiliam Apennines.) Webbia Raccolta Scr. Bot. 25(2): 353-382. (English abstracts in Biological Abstracts, Forestry Abstracts.)

Medappa, K. C., and M. N. Dana
1970. Tolerance of cranberry plants to manganese, iron, and aluminum. J. Am. Soc. Hort. Sci. 95(1): 107-110.

Smith, W. W., A. R. Hodgdon, and Russell Eggert
1947. Progress report on chemical weed control in blueberry fields. Proc. Am. Soc. Hort. Sci. 50: 233-238.

GPO 994-211

ASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

A 13.77:PNW-254

PNW-254 September 1975

RELATIONSHIP OF ROOT LENGTH TO STEM DIAMETER IN CURLLEAF MOUNTAIN-MAHOGANY

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by

Pamela S. Talley, *Range Aid*

and

J. Edward Dealy, *Range Scientist*

ABSTRACT

Measurements of root lengths and stem diameters were taken on 24 curlleaf mountain-mahogany seedlings 112 days after germination. Plants with the longest root systems possessed the largest stem diameters, indicating general plant vigor. Selection of seedlings with larger stem diameters for use in outplanting or research may increase rate of survival.

KEYWORDS: Curlleaf mountain-mahogany, *Cercocarpus ledifolius*, root system -)outplanting, stem diameter.

INTRODUCTION

Curlleaf mountain-mahogany (*Cercocarpus ledifolius*) is a small, evergreen hardwood tree (shrub form in portions of its range) which commonly grows on high mountain slopes and scattered rocky outcroppings from the west slope of the Rocky Mountains to the Cascade Range. It is found extensively at the lower edge of the ponderosa pine (*Pinus ponderosa* Laws.) forests and within the conifer zone on shallow, rocky soils (Dealy 1975).

Because of extensive use by big game for cover and forage, curlleaf mountain-mahogany is recognized as an important and desirable range species (Brandborg 1955, Kufeld 1973, Reynolds [n.d.], Smith 1954). New techniques for propagation of seedlings and new methods of outplanting are in demand by managers and nurserymen. Selection of the strongest seedlings in nursery bed

stock is important to insure survival after outplanting. Survival of mountain-mahogany seedlings, as with other desert trees and shrubs, depends partially on a deep, well-developed root system (Daubenmire 1968). This paper presents one technique to aid nurserymen and others in selecting quality seedlings with the longest root systems from nursery stock.

METHODS AND MATERIALS

Seeds from the same source were stratified for 150 days at 4° C (39° F) on filter paper moistened with distilled water. After 150 days in stratification, enough seeds had germinated for use in the study.

Twenty-four glass tubes, each 122 cm (4 ft) in length and 6.4 cm (2.5 in) in diameter, were prepared; one end was closed with a rubber stopper equipped with a 6-mm (1/4-in) glass tube for drainage. A mixture of one part peat moss and three parts loamy soil, taken from an established mahogany stand, was evenly tamped into each of the 24 tubes filling them to within 2.5 cm (1 in) of the top. These were uniformly saturated with deionized water and kept at field capacity for the duration of the study.

The tubes were placed in a plant growth chamber in six rows of four each, supported and covered by a specially built light-tight box, and secured at a 45° angle. Two germinated seeds were planted in each tube. After emergence, plants were thinned to one per tube. Roots grew against the lower edge of the glass, permitting measurement of root extension. The growth chamber was programed to simulate typical springtime conditions. Temperature was held at 24° C (75° F) during a 14-hour light period and at 5° C (41° F) during a 10-hour dark period; humidity approximated 60 percent. When roots appeared on the underside of the tube, they were measured from the soil surface to root tip every 7 days for 112 days. At that time, 7 of 24 plants had reached tube bottoms.

Plants were extracted, and their root lengths were correlated with stem diameters. Stem diameters were measured just above the root crown with vernier calipers.

RESULTS AND DISCUSSION

Average root length after 112 days was 94.5 cm (37.2 in). Average stem diameter was 0.074 cm (0.029 in).

The relationship between root length and stem diameter was significant at the 0.001 level ($r = 0.8209$) (fig. 1). The gap in the data plotted in figure 1 from 0.065 cm (0.026 in) to 0.085 cm (0.034 in) occurred naturally in the sample.

Mountain-mahogany seedlings with the largest stem diameters tend to possess longer root systems 112 days after germination. Knowledge of this relationship will be advantageous to nurserymen thinning seed beds or selecting young seedlings for container stock and to scientists selecting seedlings for research. Even though lifting of seedlings may destroy some length of the root system, this relationship indicates general plant vigor; therefore, selection of seedlings with the largest stem diameter may increase survival after outplanting or potting. Although we tend to assume that the tallest and most robust plants have the best root system, we found an indication that top growth

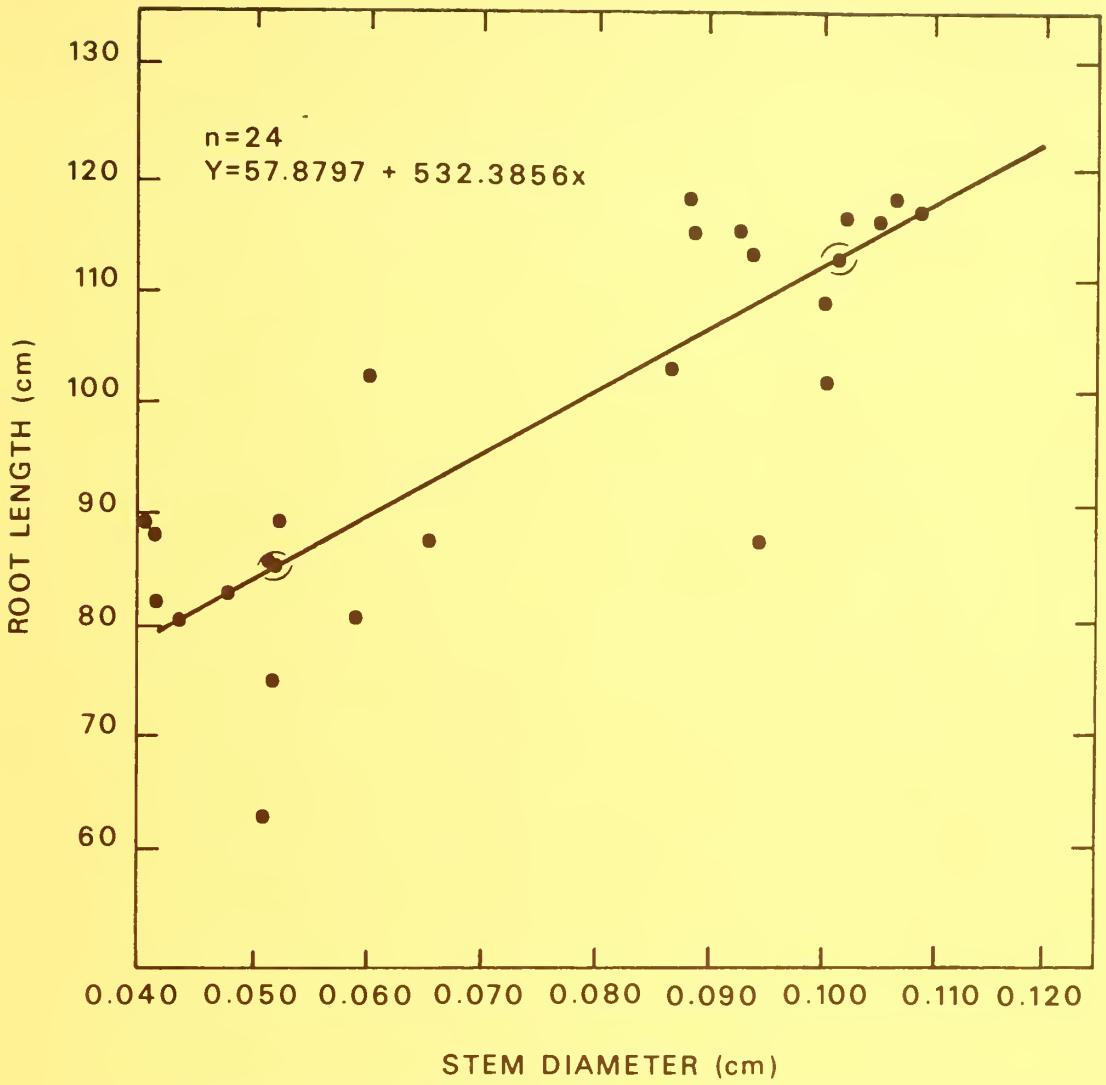

Figure 1.--Relationship between root length and stem diameter.

may even be sacrificed for root extension during the establishment phase. We observed that stems having the greatest diameter were not the tallest plants, but they did possess vigorous tops with large healthy leaves. Whether this root length/stem diameter relationship continues beyond 112 days is unknown.

LITERATURE CITED

Brandborg, Stewart M.
1955. Mountain goat in Idaho. State Idaho Dep. Fish and Game, Wildl. Bull. 2, p. 39-40.

Daubenmire, Rexford.
1968. Plant communities: a textbook of synecology. p. 191-203. Harper & Row, New York.

Dealy, J. Edward.
1975. Ecology of curlleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) in eastern Oregon and adjacent areas. Ph. D. thesis, Oreg. State Univ., p. 34-37. Corvallis.

Kufeld, Roland C.
1973. Foods eaten by the Rocky Mountain elk. J. Range Manage. 26(2):106-113.

Reynolds, Temple A., Jr.
[n.d.] The mule deer, its history, life history and management in Utah. Utah State Dep. Fish and Game, Dep. Inform. Bull. 60-4, 32 p.

Smith, Dwight R.
1954. The bighorn sheep in Idaho. State Idaho Dep. Fish and Game, Wildl. Bull. 1, p. 62-66.

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GPO 994-335

ASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-255 September 1975

RED SQUIRREL RESPONSE TO CLEARCUT AND SHELTERWOOD SYSTEMS IN INTERIOR ALASKA

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by

Jerry O. Wolff [1/]

and

John C. Zasada, *Silviculturist*

ABSTRACT

Population response of red squirrels to clearcut and shelterwood silvicultural systems in interior Alaska was determined by counting the population before and after cutting. Following harvest, all territories from the clearcuts were vacated and the number of squirrels in the shelterwood decreased from 1 per 0.69 ha to 1 per 2.0 ha. The squirrel population in the adjacent control area and along the cutting area boundary remained stable.

KEYWORDS: Red squirrels, *Tamiasciurus hudsonicus*, shelterwood cutting method, clearcutting systems.

[1/] Jerry O. Wolff was a part-time Station employee at the time this manuscript was prepared. He is now with the Museum of Vertebrate Zoology, University of California, Berkeley.

Red squirrels (*Tamiasciurus hudsonicus*) are widely distributed throughout the coniferous forests of interior Alaska (Hall and Kelson 1959). These animals inhabit mature forests and feed primarily on seeds of white or black spruce (*Picea glauca; Picea mariana*) (Dice 1921, Murie 1927, Brink and Dean 1966). They are solitary; males and females are equally aggressive in defending individual territories ranging in size from 0.4 to 1.3 ha[2/] (Klugh 1927, C. C. Smith 1965). In a homogeneous white spruce forest, this type of social behavior tends to distribute the animals in a regular pattern. Populations and territory size are quite stable; however, they are known to fluctuate in direct response to food availability (C. C. Smith 1968, 1970; M. C. Smith 1968).

Forest harvesting is a common means of altering the white spruce type, and thus red squirrel habitat, in the boreal forest. Clearcutting will obviously result in habitat destruction and population decline. However, the effects of stand density reduction (e.g., a shelterwood) and the squirrel response along the periphery of a clearcut are not known. The objective of this paper is to examine the short-term response of a squirrel population to the clearcut and shelterwood silvicultural systems.

STUDY AREA

The study area was located in a mature white spruce stand within the Bonanza Creek Experimental Forest 30 km southwest of Fairbanks, Alaska (64^{o} 50' N. lat.). The largest spruce were over 125 years old, approximately 30 m high with a diameter at breast height of 40 cm. Quaking aspen (*Populus tremuloides*), alder (*Alnus crispa*), and paper birch (*Betula papyrifera*) were the only other large vascular plants on the study area.

The study area was divided into three clearcuts--two 1-ha and one 1.6-ha--and three shelterwoods each 2.4 ha in area (fig. 1). The average density of white spruce before logging was 472 trees per ha (189/acre). After harvest, the clearcuts had no trees standing, and the shelterwoods had 81 trees per ha (33/acre).

METHODS

Before harvest in June 1972, all squirrel middens in the study area and within a 70-m zone around the cutting units were counted and mapped. Diameter of an average size territory is 70 m.[3/] A midden is a large accumulation of spruce cone bracts stripped by the squirrel which cover an underground food cache (M. C. Smith 1968). A midden count can be used as an index to estimate population size since each active midden is the work of one squirrel and each squirrel has no more than one midden (Gordon 1936, Clarke 1939, Kilham 1954, C. C. Smith 1965, M. C. Smith 1968). A similar count was made in the fall of 1974, 2 years after all designated trees had been cut and removed. Field observations were made to determine if any squirrel occupied more than one midden or if territorial boundaries overlapped. Squirrels were not marked, and thus some of these observations were subjective. If a midden had been moved to less than 15 m from its original location, it was mapped as being in the same place.

[2/] W. D. Fitzwater, Jr. The red squirrel: territorialism, activity, census methods. M.S. thesis, New York State College of Forestry, Syracuse, 117 p. 1941.

[3/] D. P. Streubel. Food storing and related behavior of red squirrels (*Tamiasciurus hudsonicus*) in interior Alaska. M.S. thesis, University of Alaska, Fairbanks, 56 p. 1968.

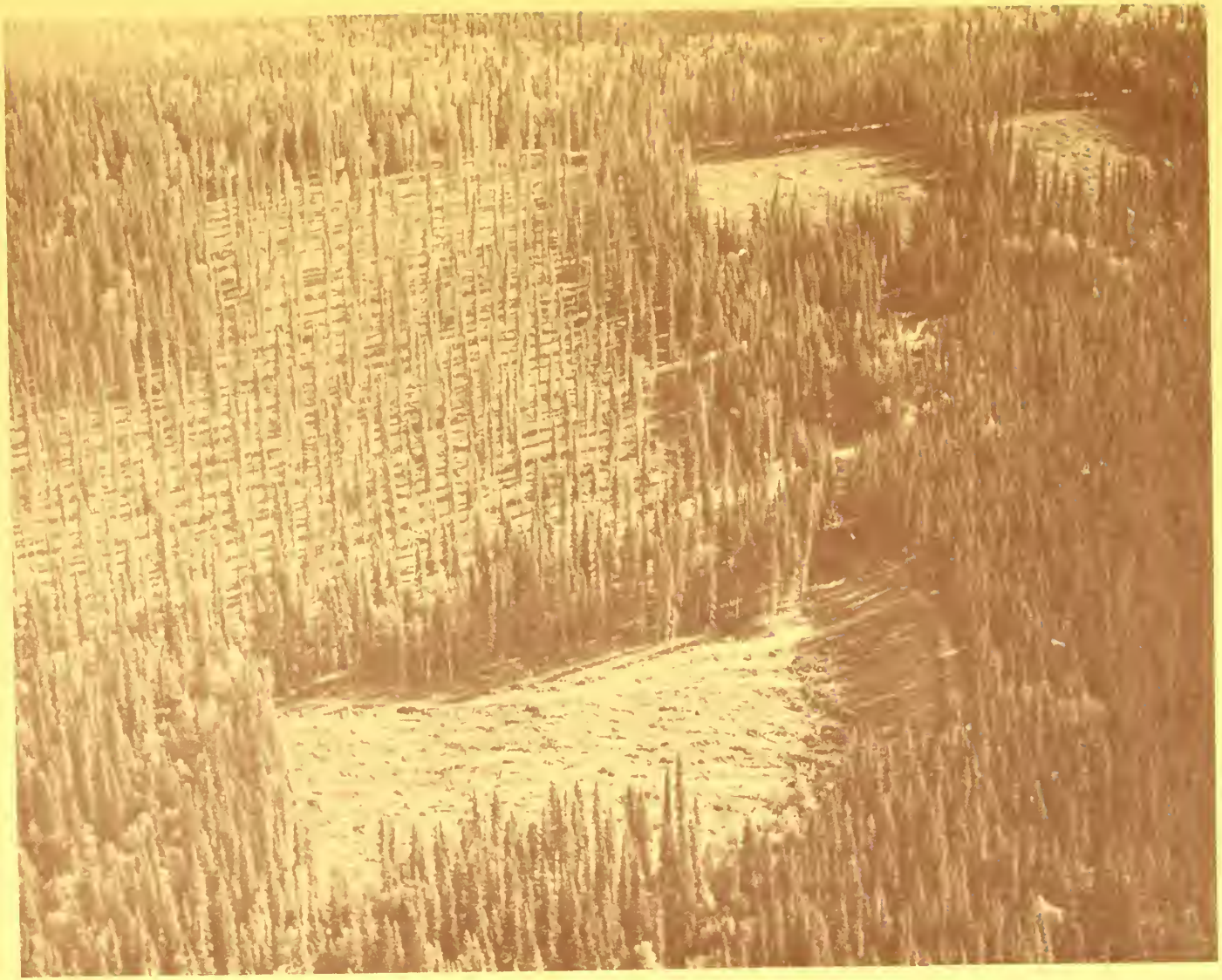

Figure 1.--Aerial photo of study area after logging.

RESULTS AND DISCUSSION

Before harvest (1972), there were 39 middens in the total cutting and peripheral area of 25.4 ha or 1 squirrel per 0.65 ha. After harvest (1974), the number of animals was reduced to 23. The distribution of these squirrel middens is shown in figure 2. All territories from the clearcuts were vacated, but squirrels were observed in the clearcut in the summer of 1973 at old middens. The number of squirrels in the shelterwoods decreased from 1 squirrel per 0.69 ha in 1972 to 1 per 2.0 ha in 1974 (table 1). Animals which remained in the shelterwood areas increased their home range and incorporated some of the adjacent control area into their territories. Territory size may be

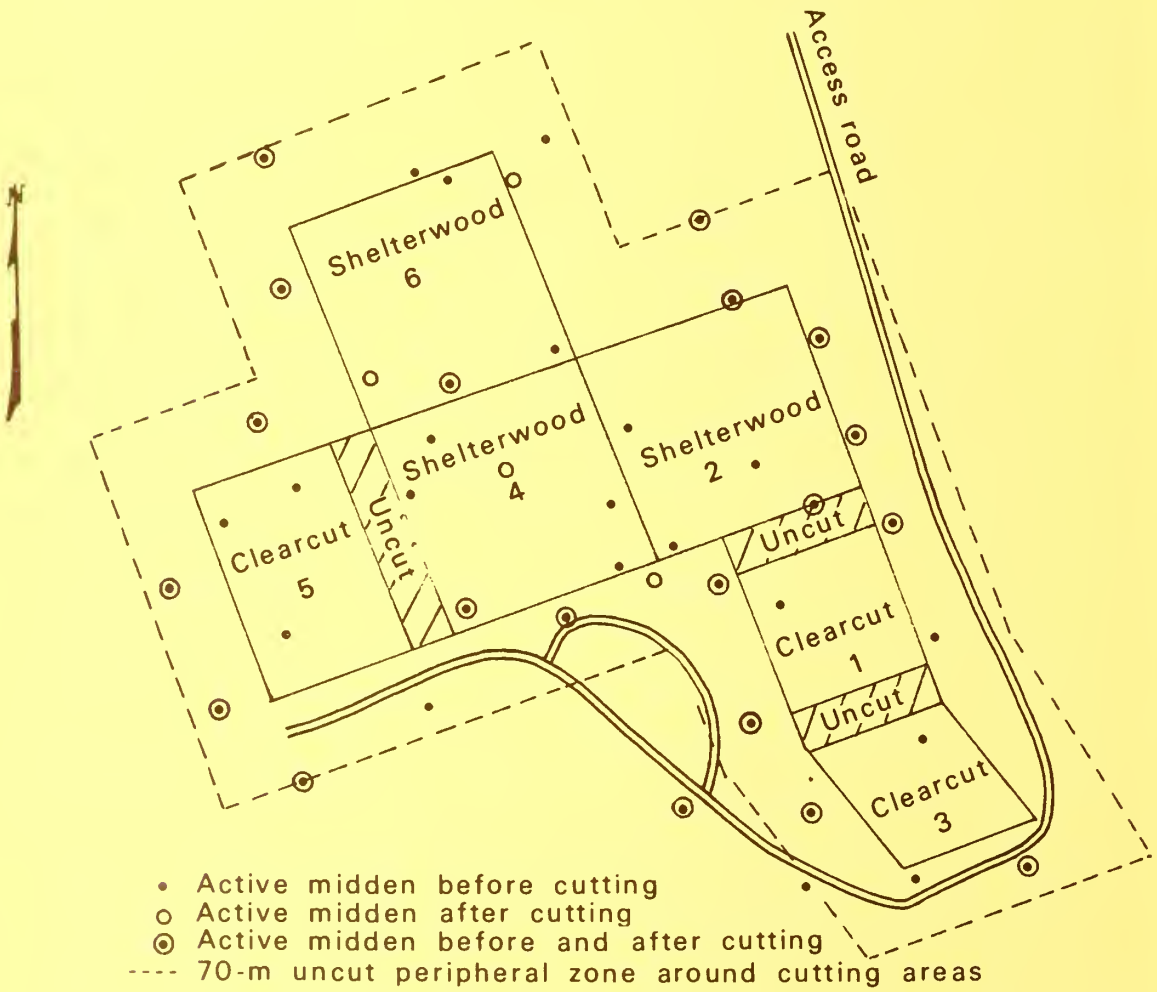

Figure 2.--Map of the cutting units and peripheral control area showing location of middens before and after logging.

TABLE 1.--*Description of experimental areas showing territory size before and after logging*

Treatment	Area	Number of hectares per squirrel	
		Before logging (1972)	After logging (1974)
	Hectares		
Clearcut:			
Unit 1	1.0	1.00	0
Unit 3	1.0	1.00	0
Unit 5	1.6	.53	0
Average		.84	0
Shelterwood:			
Unit 2	2.4	.80	2.40
Unit 4	2.4	.48	1.20
Unit 6	2.4	.80	2.40
Average		.69	2.00
Uncut forest:			
Adjacent to study area	14.6	.63	[1/].76
3 km from study area[2/]	21.0	[3/].75	.66

[1/] Three squirrel middens along road right-of-way and log decks were vacated.

[2/] Gary Searing. Aggressive behavior and population regulation of red squirrels (*Tamiasciurus hudsonicus*) in interior Alaska. M.S. thesis, University of Alaska, Fairbanks, 74 p. 1975.

[3/] 1971.

adjusted to the quantity of food contained in the territory (C. C. Smith 1965, M. C. Smith 1968). Patton (1974) found that densities of Abert's squirrels decreased with a more open crown canopy and wider spacing of ponderosa pine trees. In the uncut areas around the harvested units, population densities dropped from 1 squirrel per 0.65 ha in 1972 to 1 per 0.76 ha in 1974. This change can be at least partially related to vacated middens in or close to road rights-of-way or log decks. In a mature spruce stand approximately 3 km from our study area, the population was 1 squirrel per 0.75 ha in 1971 and 1 per 0.66 ha in 1974.[4/] Squirrel densities in the past 10 years ranged from

[4/] Gary Searing. Agressive behavior and population regulation of red squirrels (*Tamiasciurus hudsonicus*) in interior Alaska. M.S. thesis, University of Alaska, Fairbanks, 74 p. 1975.

1 per 0.65 ha to 1 per 5.3 ha, with the lowest densities during years following cone-crop failure[5] (also see footnotes 3 and 4).

Cone production from 1970 to 1973 was observed in detail in three mature white spruce stands within 5 km of the study area and less intensively in the study area. These observations indicated that 1970 and 1972 were excellent cone and seed years. All dominants and codominants produced at least 500 cones, and many produced more than 1,000 cones. No cones were observed on any trees in 1971; in 1973 the majority of trees produced less than 50 cones, and the most observed on any tree was less than 200. Thus, the squirrels in the study area were probably most dependent on cones cached in 1972 with a small contribution from the 1973 crop.[6]

SUMMARY

Short-term response under the particular set of management conditions imposed here resulted in the squirrels' vacating clearcuts and in reduction of their numbers in shelterwoods. Populations in adjacent uncut stands remained stable, or increased slightly. The long-term suitability of the shelterwood will be determined both by the response of squirrels to the more open stand conditions, especially the spacing of cone-bearing trees, and by cone production.

LITERATURE CITED

Brink, C. H., and F. C. Dean
1966. Spruce seed as a food of red squirrels and flying squirrels in interior Alaska. J. Wildl. Manage. 30(3):503-512.

Clarke, C. H. D.
1939. Some notes on hoarding and territorial behaviour of the red squirrel (*Sciurus hudsonicus* (Erxleben)). Can. Field Nat. 53(3):42-43.

Dice, L. R.
1921. Notes on the mammals of interior Alaska. J. Mammal. 2(1):20-28.

Gordon, K.
1936. Territorial behavior and social dominance among Sciuridae. J. Mammal. 17(2):171-172.

Hall, E. R., and K. R. Kelson
1959. The mammals of North America. 2 vols. The Ronald Press, New York.

Kilham, L.
1954. Territorial behaviour of red squirrel. J. Mammal. 35(2):252-253.

Klugh, A. B.
1927. Ecology of the red squirrel. J. Mammal. 8(1):1-32.

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[5] P.V. Krasnowski. Aspects of red squirrel (*Tamiasciurus hudsonicus*) population ecology in interior Alaska. M.S. thesis, University of Alaska, Fairbanks, 63 p. 1969.

[6] Unpublished data on file at the Institute of Northern Forestry, USDA Forest Service, Fairbanks, Alaska.

Murie, O. J.
1927. The Alaska red squirrel providing for winter. J. Mammal. 8(1):37-40.

Patton, D. R.
1974. Characteristics of ponderosa pine stands selected by the Abert's squirrel for cover. Diss. Abstr. 35(4):1471B.

Smith, C. C.
1965. Interspecific competition in the genus of tree squirrels *Tamiasciurus*. Ph. D. thesis., Univ. Wash., Seattle. 269 p.

Smith, C. C.
1968. The adaptive nature of social organization in the genus of tree squirrels *Tamiasciurus*. Ecol. Monogr. 38(1):31-63.

Smith, C. C.
1970. The co-evolution of pine squirrels (*Tamiasciurus*) and conifers. Ecol. Monogr. 40(3):349-371.

Smith, M. C.
1968. Red squirrel responses to spruce cone failure in interior Alaska. J. Wildl. Manage. 32(2):305-317.

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USDA FOREST SERVICE RESEARCH NOTE

.79:PNW-256

PNW-256 July 1975

DDT RESIDUE ACCUMULATION AND DECLINE IN KIDNEY FAT OF LAMBS GRAZING SPRAYED FOREST RANGE

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DEC 10 1975
SCI., TECH. & AGR. DIV.

by

Gerald S. Strickler, *Plant Ecologist*

ABSTRACT

DDT residues in fat of weaner lambs grazing 1, 2, 6, 10, and 14 weeks (five treatment groups) in forests sprayed with DDT for Douglas-fir tussock moth control increased rapidly up to 2 weeks, then decreased. Following removal of lambs to unsprayed feed for 14 to 22 weeks, fat residue levels declined, but only those in the 1- and 2-week treatments fell significantly below the 5-p/m tolerance level.

KEYWORDS: DDT residue, DDT monitoring, DDT in sheep.

INTRODUCTION

As part of the monitoring program of the 1974 Douglas-fir Tussock Moth Project,[1] a study was made of DDT residues in kidney fat, muscle tissue, rumen, and feces of lambs grazing a forested range aerially sprayed with approximately 0.75 pound of DDT per acre.

Much interest in the study results has been generated by ranchers and agricultural organizations concerning the buildup and decline of DDT residue in the lambs relative to the 5-p/m tolerance level[2] in fat of marketable livestock. Analyses of the fat samples have been completed and are reported here. This should be considered a preliminary report; a complete report of residues in vegetation and all lamb tissue samples will be made following completion of the analyses.

METHODS

Spraying on the allotment was completed on June 24. On June 26, 120 weaned lambs, approximately 5 months old and 70 pounds in weight, were trucked to the allotment, ear tagged, and separated into six groups of 20 lambs each. Within groups, lambs were randomly assigned to one of six, three-lamb lots for tissue sampling. Two lambs per group were designated as replacements if needed.

The control group (C) was immediately trucked to an unsprayed allotment, placed with a 1,800-head ewe-lamb band, and the first three-lamb lot slaughtered at this time for tissue samples. The nearest spraying of DDT was 6 air miles from areas grazed on the unsprayed allotment; therefore the likelihood of DDT contamination of forage utilized by the ewe-lamb band was zero. This was later verified by residue analysis of vegetation samples.

The remaining five groups began grazing the DDT-sprayed allotment. These groups (treatment groups) are identified by the numbers 1, 2, 6, 10, and 14, corresponding to the number of weeks a group grazed the DDT-sprayed forage. After grazing the designated time, a group was corralled, 3 animals sacrificed, tissue samples taken, and the remaining 17 lambs trucked to the unsprayed allotment. Three animals were sacrificed and tissue samples taken from the control group when each treatment group was placed on the unsprayed allotment.

Once on the unsprayed allotment, the five sample lots remaining in each treatment group were sequentially slaughtered at various times during a 22-week period. Time of sampling lots varied for each group due to the feasibility and efficiency of gathering the lambs relative to the location and movement of the ewe-lamb band. Number of lambs available for each treatment varied between 17 and 20 because of death, lost sheep, and the use of the two replacement lambs in groups 2, 6, and 10 as a final sample.

The grazing season on both allotments terminated 14 weeks after the study began. Lambs remaining at this time (October 1) were put on unsprayed wheat stubble for 6 weeks (until November 12) and then lot-fed alfalfa-orchardgrass hay until the last samples were taken on January 8.

Before each tissue sample was taken from a carcass, knives were

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[1] USDA-USDI Environmental Statement. Cooperative Douglas-fir Tussock Moth Pest Management Plan. Idaho-Oregon-Washington. U.S. Department of Agriculture, Forest Service. 301 p., mimeographed. December 1973.

[2] Federal Register, Vol. 39, No. 157, Tuesday, August 13, 1974. Rules and regulations, Part 180 - Tolerance and exemptions from tolerances for pesticide chemicals in or on raw agricultural commodities, p. 28977-28978.

cleaned and thoroughly rinsed with acetone. Disposable surgical gloves were also rinsed with acetone and disposed of after each tissue sampling. Care was taken not to contaminate samples through contact with surrounding tissue. Kidney fat samples were taken, after the viscera had been dropped, by pulling out the kidney and attached fat, severing it from the body cavity, and "peeling" the fat from the kidney.

Tissue samples were placed in acetone-rinsed cans, frozen, and shipped on dry ice to the laboratory. Samples were analyzed by gas chromatography using a modified Mills, Onley, Gaither procedure.[3/] Log transformation of residue values was used to yield more realistic means and confidence intervals. Differences in mean residue of DDT among the five treatment groups (control groups were not tested) when they were removed from the sprayed allotment were tested by analysis of variance using the logarithmic transformed values. Mean residues of lamb groups in the five treatments on the unsprayed allotment were tested with a one-tailed "t" test for those levels which were significantly less than 5-p/m tolerance level.

All residues reported are the sum of DDT (p,p' and o,p' isomers) and the metabolites, DDE and DDD, in parts per million on the total lipid basis.

[3/] Environmental Protection Agency. Manual of analytical methods. Section 5 A, (1) - Analysis of human or animal adipose tissue. Pesticide and Toxic Substances Effects Laboratories. National Environmental Research Center, Research Triangle Park, North Carolina. 1972.

RESULTS AND DISCUSSION

Low mean residues in the control kidney fat samples throughout the study showed not only that the lambs were relatively free of DDT when the study began but also there was no DDT contamination of forage on the unsprayed allotment during the 14-week season (table 1).

Mean residues in kidney fat for the five treatment groups were significantly different (probability <0.05). After grazing 1 and 2 weeks on sprayed forage, residues were 14.99 and 32.85 p/m, respectively; then, as expected, mean residues decreased in lambs grazing 6, 10, and 14 weeks on sprayed forage.

Residue in fat decreased rapidly in groups 1, 2, and 6 after removal to the unsprayed allotment (fig. 1), but only mean residues in groups 1 and 2 dropped significantly (probability <0.025) below the 5-p/m tolerance level--both after 8 weeks on unsprayed forage. Decline in residues in groups 10 and 14 was slower, and no means went below 5 p/m.

Differences in rates of loss among groups resulted from a variety of causes operating at different times. Early loss of DDT residue from forage through rainwash, bacterial action, volatilization, and dilution (fast forage growth) would decrease DDT ingestion. Through the season, lambs gained in weight from approximately 70 to 113 pounds with a greater degree of fatness in later samples, suggesting more dilution of DDT ingested. Also, the variation in decrease and increase noted in the isomers and metabolites during the course of the study would affect loss rates.

This paper is concerned with the marketability of lambs; and the rates of loss will be more fully

Table 1.--*Mean and confidence interval (95-percent probability) of DDT residues in kidney fat of sheep grazing 1 to 14 weeks on a DDT-sprayed allotment and subsequently on an unsprayed allotment. 1974 Douglas-fir Tussock Moth Project*[1/]

Number of weeks grazing	Treatment group					
	Control	1	2	6	10	14
	p/m DDT					
On DDT-sprayed allotment:						
1 (July 3)		14.99 (48.18-4.66)				
2 (July 10)			32.85 (70.13-15.39)			
6 (Aug. 6)				26.03 (29.72-22.81)		
10 (Sept. 5)					14.20 (22.01-9.16)	
14 (Oct. 2)						26.88 (38.00-19.02)
On unsprayed allotment:						
0	[2/] 0.046 (0.191-0.011)					
1	0.035 (0.066-0.018)	9.46 (24.22-3.70)				17.65 (27.06-11.52)
2	0.053 (0.118-0.024)		7.91 (8.21-7.61)		23.19 (45.34-11.87)	19.30 (31.74-11.74)
3		3.53 (5.64-2.21)		11.10 (34.24-3.60)		
4			2.58 (11.44-0.58)	8.56 (15.09-4.86)	12.00 (21.67-6.65)	
6	0.067 (0.161-0.028)				19.28 (178.52-2.08)	15.92 (26.25-9.65)
8		0.84 (1.22-0.57)	3.04 (4.26-2.17)	5.54 (7.22-4.26)		
10	0.100 (0.156-0.064)			6.51 (9.85-4.30)	9.16 (18.12-4.63)	10.59 (20.77-5.40)
14	*0.096 (0.134-0.069)	0.93 (2.52-0.35)	2.02 (3.90-1.04)	4.42 (10.46-1.86)	7.54 (14.36-3.96)	9.52 (14.89-6.09)
18			1.10 (2.22-0.54)	*3.36 (118.72-0.10)	*5.97 (10.38-3.44)	
19		0.85 (1.38-0.52)				
22			*1.58 (22.74-0.11)			

[1/] Values are means of 3-lamb samples except for 2-lamb samples shown with an asterisk (*) and are the sum of DDE, DDD, o,p' DDT, and p,p' DDT. The lower level of detectability is 0.010 p/m. Means and confidence intervals were derived from a logarithmic transformation of the residue values.

[2/] Control sample taken at beginning of study.

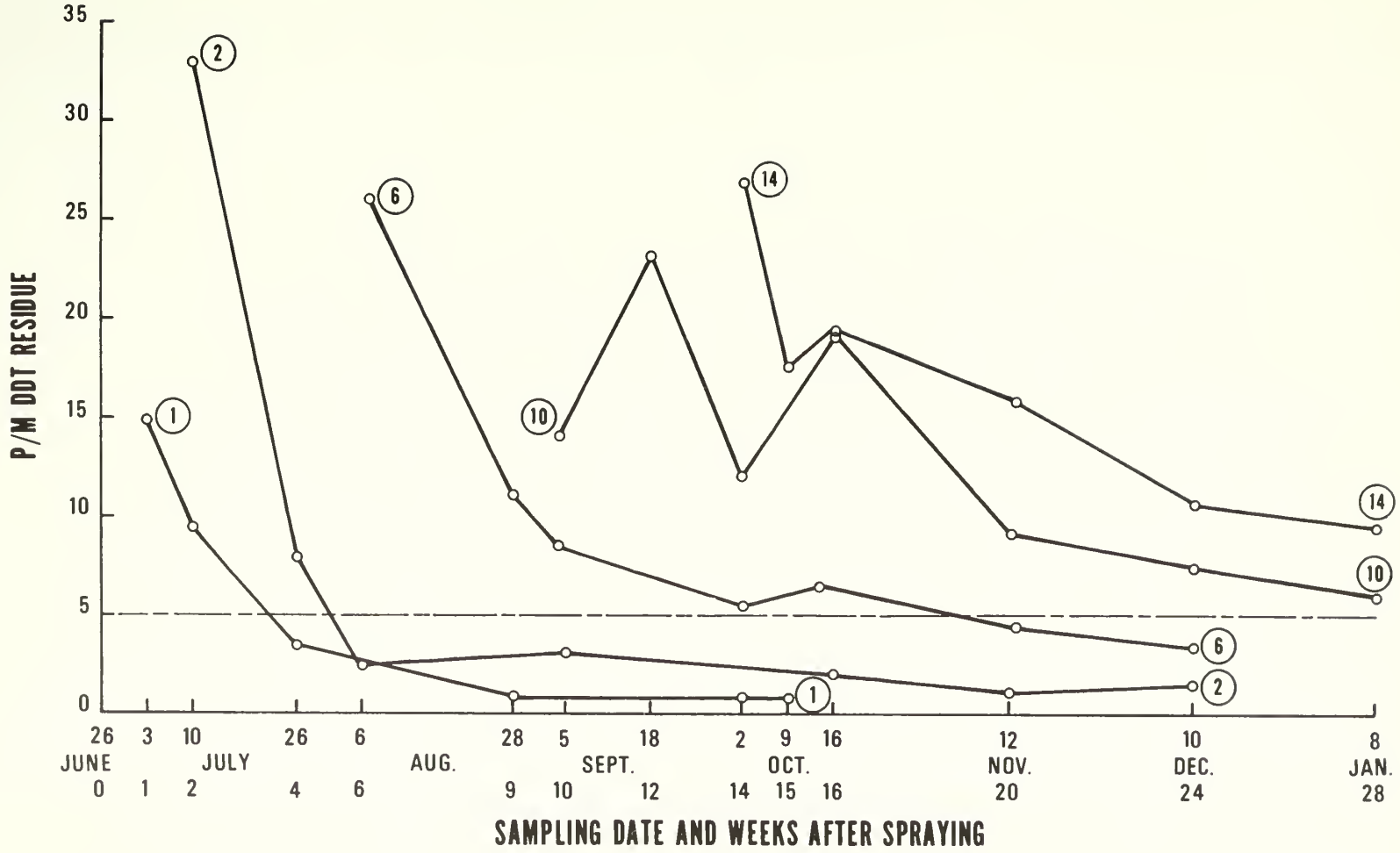

Figure 1.--*Decline of DDT residues in kidney fat of sheep after grazing 1, 2, 6, 10, and 14 weeks on DDT-sprayed forested range.*

covered following further analyses of DDT residues in vegetation, rumen, and fecal material. Under the conditions of this study, only the lambs grazing 2 weeks or less on the DDT-sprayed allotment were marketable--the group 1 lambs after August 28 and the group 2 lambs after September 5. Establishing a lower risk (probability <0.01) of saying the average level is below 5 p/m if it really isn't would not change the date for the group 1 lambs but group 2 lambs would not be marketable until after November 12.

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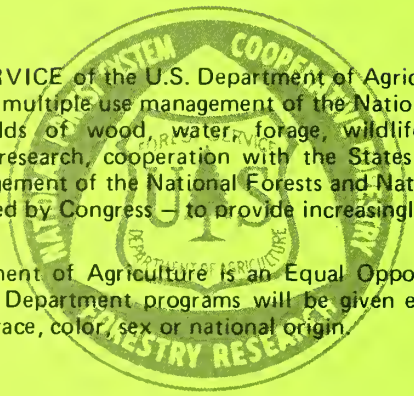

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EVALUATING DAMAGE CAUSED TO A CAMPGROUND BY DOUGLAS-FIR TUSSOCK MOTH

by

Boyd E. Wickman, *Principal Insect Ecologist*

and

Donald A. Renton,[1/] *Planning Systems Coordinator*

ABSTRACT

The impact of insect defoliation on recreation values can be an important factor in an economic analysis of overall damage. Tree mortality and top-kill were tallied and evaluated on a small campground in 1970. Cleanup costs involving hazardous trees and dead tops amounted to $23.75 per camp unit. When esthetic values were assigned to trees, the insect damage costs increased to $126.88 per camp unit. Campground trees should be assigned some replacement value rather than their timber value to aid the pest management specialist in determining the level and kind of suppression technique to be applied against a given pest.

KEYWORDS: Economic evaluation, insect damage control (forest), recreation.

[1/] Former District Ranger, USDA Forest Service, Cedarville, Calif., now in Forest Service Systems Application Unit, Colorado State University, Fort Collins, Colo.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

The Douglas-fir tussock moth (*Orgyia pseudotsugata* McD.) can cause heavy defoliation of white fir (*Abies concolor* (Gord. and Glend.) Lindl.), and this may result in large amounts of tree mortality and top-kill (Wickman 1963). In 1964-65, this insect caused severe damage on 450 acres (182 ha) surrounding a U.S. Forest Service campground at Stowe Reservoir in the Warner Mountains, Modoc National Forest (Wert and Wickman 1970). The impact of insect defoliation on recreation values can be an important factor to include in overall estimates of damage. This infestation offered a unique opportunity to evaluate damage to trees on a recreation site after a Douglas-fir tussock moth infestation. Consequently, a survey on the impact on the Stowe Reservoir campground was made in cooperation with the Warner Mountain District of the U.S. Forest Service in the summer of 1970.

FEATURES OF THE CAMPGROUND

The campground is situated in a small basin at about 6,000-foot (1,829-m) elevation. It is composed of eight camp units (table and fireplace) scattered over 3 acres (1 ha). The campground also has piped spring water, four pit toilets, and roads leading to each unit. The estimated replacement value was $1,500 per unit or $12,000 for the entire campground in 1970. In addition, $650 per year was spent on maintenance and cleanup (1970 costs). Visitor use steadily increased from 1965 to 1970; recreation visits in 1970 totaled an estimated 1,000 visitor days. The majority of the visits were for overnight camping.

Esthetic features are difficult to quantify. The campground is surrounded by a 60- to 70-year-old stand of white fir with some scattered Washoe pine (*Pinus washoensis* Mason & Stockwell), ponderosa pine (*Pinus ponderosa* Laws.), and western juniper (*Juniperus occidentalis* Hook.). When the basin was first logged, about 75 years ago, the trees in the campground area were not cut. Consequently, there are 48 white fir trees over 20-inch (51-cm) d.b.h. in the campground. The vistas from campsites vary from forested hillside, a small pond (the reservoir) which is silting into a verdant meadow, and craggy Bear Mountain immediately to the north. The campground is not close to developed summer recreation facilities; but outdoor activities available nearby include hiking, looking for petrified wood, and deer hunting. These activities, plus the beautiful mountain scenery and availability for overnight use, account for the increased use of the campground.

THE TUSSOCK MOTH OUTBREAK AND TREE DAMAGE

In 1964, larvae of the Douglas-fir tussock moth were first detected on white fir in the campground as a result of complaints from campers. Larvae and their fecal pellets fell on picnic tables, cars, and tents, causing considerable annoyance. There were also reports that the garbage collectors suffered skin irritation from contacting the poisonous hairs of the caterpillar. Because of the insects' nuisance and ability to damage trees, the Stowe Reservoir campground and 200 acres (81 ha) of infestation surrounding the campground were sprayed with Malathion on August 2. The insecticide failed to control larval populations or prevent damage. By late summer 1964, 450 acres (182 ha) surrounding the campground were severely defoliated and trees were dying (fig. 1). An infested area of 2,098 acres (849 ha) was treated with DDT on June 29 and July 4, 1965. The population was decimated within

Figure 1.--White fir mortality in the Stowe Reservoir area after the 1964-65 outbreak of Douglas-fir tussock moth.

10 days due to the insecticide and a natural virus. There was no further feeding damage, but thousands of heavily defoliated trees in the basin subsequently died or suffered top-kill (Wert and Wickman 1970).

Three types of damage occurred in the campground: tree mortality (fig. 2), top-kill (fig. 3), and thin foliage which indicated a weakened condition and possible top-kill or death.

Figure 2.--White fir mortality after heavy defoliation by the Douglas-fir tussock moth (Stowe Reservoir, 1967).

Figure 3.--White fir top-killed by Douglas-fir tussock moth defoliation. Trees are directly over a campsite (Stowe Reservoir, 1970).

Before the infestation, there were 22 pine and 348 white fir trees in the campground, 6- to 32-inch (15- to 81-cm) d.b.h. (there was little regeneration because of human and vehicular traffic). By 1970, 7 percent of the fir trees had been killed outright, and another 5 percent were top-killed or had thin crowns (table 1). The merchantable dead trees were not salvaged for milling because of their low saw-log value and the desire to disturb the campground as little as possible.

TABLE 1.--*Number and percent of all white fir trees by diameter class and damage class, Stowe Reservoir campground, Modoc National Forest, July 1970*

D.b.h. class (inches)	Undamaged		Killed		Top-killed		Thin foliage		Total damage	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
6-9	162	95.9	6	3.6	0	0	1	0.5	7	4.1
10-19	105	81.4	17	13.2	4	3.1	3	2.3	24	18.6
>20	40	80.0	2	4.0	8	16.0	0	0	10	20.0
Total number and weighted average percent	307	88.2	25	7.2	12	3.4	4	1.2	41	11.8

EVALUATION OF DAMAGE ATTRIBUTED TO THE TUSSOCK MOTH INFESTATION

It is extremely difficult to evaluate the economic damage that insects, or any other agent, may inflict on forest trees in recreation sites. Such trees have a value at least equal to their saw-log value, but this does not take into account the value of the tree in situ or its contribution to the esthetics of the site. Therefore, two analyses are presented here--one on actual costs, the other on unit value per tree per camp. They are strictly examples because there are no precise standards for evaluating tree esthetics on wildland recreation areas.

1. *Values based on actual costs.* Dead trees and tops from top-killed trees often should be removed from Forest Service recreation sites because they are hazardous (Paine 1971). The costs of tree removal in 1970 were:

Tree felling and slash disposal of dead trees	$ 90
Topping of top-killed trees	100
Total	$190

Removal of damaged trees amounted to $23.75 per camp unit.

2. *Values based on a calculated unit value per tree per camp.*[2/] The estimated replacement value per camp unit at Stowe Reservoir was $1,500 in 1970. There were 348 white fir and 22 pine trees in the campground before

[2/] Analysis suggested by Lee Paine, Pathologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

the infestation. If we divide number of trees per unit into the capital investment per unit we obtain a value per tree that relates to its in situ esthetic value (if we assume that the unit would have some lesser value without the trees).

Total trees	Camp units	Trees per unit	Esthetic value per tree ($1,500÷46)	Trees killed	Value lost in dead trees
370	8	46	$33	25	$825

Esthetic value lost in dead trees	$ 825
Felling, removal, and topping of trees	190
	$1,015

Costs from insect damage were $126.88 per camp unit by this analysis.

DISCUSSION

Timber losses caused by insects are usually figured in board- or cubic-foot volume and relate to wood fiber made unavailable for manufacturing. The impact of insects feeding on trees in recreation sites needs to be evaluated in a totally different light. Most of the trees in this campground have been growing for 50 to 200 years. They are needed for shade, screening, and their esthetic qualities. Obviously, each tree has a unique and high value much greater than its saw-log value.

When the potential damage that may be caused by an insect infestation in a recreation site is considered, the anticipated costs of removal of hazardous trees should be augmented by replacement costs of camp units. For future cost-benefit analysis in forest management models, it would be helpful if landscape architects or recreation foresters would consider campground trees as part of the total investment and make some effort to assign replacement values to them as they do tables, stoves, and toilets. This would aid the pest management specialist in determining the level and kind of suppression technique to be applied against a given pest to protect those values.

LITERATURE CITED

Paine, L. A.
1971. Accident hazard. Evaluation and control decisions on forested recreation sites. USDA For. Serv. Res. Pap. PSW-68, 11 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wert, Steven L., and Boyd E. Wickman
1970. Impact of Douglas-fir tussock moth. . . color aerial photography evaluates mortality. USDA For. Serv. Res. Pap. PSW-60, 6 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wickman, Boyd E.
1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PSW-7, 15 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

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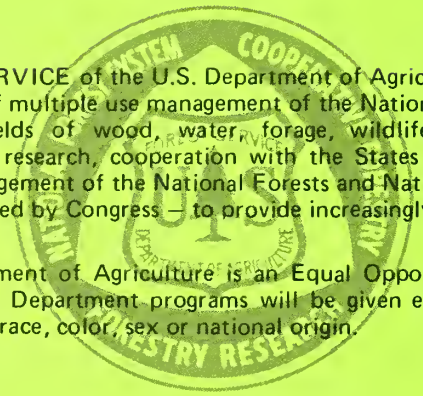

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USDA FOREST SERVICE RESEARCH NOTE

PNW-258 September 1975

RESPONSE OF WESTERN LARCH TO CHANGES IN STAND DENSITY AND STRUCTURE

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by

K. W. Seidel, *Silviculturist*

ABSTRACT

The 5-year growth response of a 55-year-old, even-aged western larch stand thinned from above and from below to a wide range of stocking levels was measured in eastern Oregon. Both basal area and volume growth increased as stand density increased for both thinning methods. Diameter growth increased moderately in response to decreasing stand density when thinned from above and from below, but height growth was not affected by thinning intensity or method.

Thinning from above does not appear to be a sound silvicultural practice in previously unmanaged larch stands of this age because the intermediate and suppressed trees with small crowns are unable to respond to the additional growing space. And, because of mortality caused by windthrow and exposure, net volume growth is significantly less than in plots thinned from below.

Keywords: *Western larch,* Larix occidentalis, *thinnings(-stand volume, stand structure, stand density.*

As forest management is intensified in the mixed-conifer forest of eastern Oregon, information is needed on growth and yield of managed stands so managers can formulate stocking level regimes to meet their objectives. Results from thinning studies provide some of the basic data on which control of stocking level is based.

Although some information is available on the response of western larch (*Larix occidentalis* Nutt.) to thinning from studies in Montana and British Columbia (Roe and Schmidt 1965, Illingworth 1964, Thompson 1969), little is known about the growth of managed larch stands in eastern Oregon. Seidel (1971) reported on the effects of thinning on a 33-year-old larch stand in northeastern Oregon, but additional studies are needed.

In 1970, a study was begun in an even-aged larch stand in northeastern Oregon. The purpose of this study was

to obtain data on growth of larch after thinning to several density levels and by two thinning methods. This paper reports results from the first 5-year period of the study.[1]

STUDY AREA AND METHODS

The study is located on Boise-Cascade land about 6 miles (9.7 km) northwest of Elgin, Oregon, on a gentle east-facing slope at an elevation of about 3,000 feet (914 m). The stand was 55 years old when first thinned in 1970 and has a site index of about 83 feet (25 m) at age 50.[2] The soil is classified as a Tolo silt loam, which is a well-drained Regosol developed from dacite pumicite originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. It is underlain at a depth of about 4 feet (1.2 m) by a buried soil developed from basalt.

The larch stand on the study area is a seral stage of an *Abies grandis/ Pachistima myrsinites* plant community (Franklin and Dyrness 1973). Many genera of shrubs and herbs such as *Thalictrum, Symphoricarpos, Smilacina, Trifolium, Spiraea, Vicia, Rosa, Fragaria, Osmorhiza,* and *Anemone* are found on the study area. Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), and Engelmann spruce (*Picea engelmannii* Parry) are also present.

The study consists of a 4 by 2 factorial randomized block design replicated two times for a total of sixteen 0.286-acre (0.116-ha) plots. The first factor is density and consists of four levels: 50, 90, 130, and 170 ft^2 of basal area per acre (11.5, 20.7, 29.8, and 39.0 m^2 per hectare). The second factor is thinning method; these are: above (cutting largest trees--dominants and codominants) and below (cutting smallest trees--suppressed, intermediate, and smaller codominants). Analyses of variance were used to test significance of treatment effects, and regression analyses related diameter, basal area, and volume growth to residual basal area.

All plots were well stocked before treatment, ranging from 191 to 226 ft^2 of basal area per acre (43.8 to 51.9 m^2 per hectare) (table 1). Trees were spaced from 8.5 to 10.3 feet (2.6 to 3.1 m) apart, and average d.b.h. ranged from 8.2 to 9.8 inches (20.8 to 24.9 cm). All plots after thinning from above contained 2 to 8 percent of Douglas-fir, grand fir, or Engelmann spruce except one plot where 22 percent of the residual basal area was grand fir and Douglas-fir. All trees in plots thinned from below were larch.

Plots were thinned with a Drott "feller-buncher."[3] This machine utilizes shears and a grapple mounted on a 25-foot (7.6-m) boom with a crawler tractor undercarriage. Operation of this equipment required prior removal of all trees (clearcut) in swaths 20 feet (6.1 m) wide. Swaths were spaced 50 feet (15.2 m) apart and oriented east and west through the stand (fig. 1). The "feller-buncher" then moved along these clearcut strips, reaching 25 feet (7.6 m) into the thinning strips to cut and remove the entire tree. Some variation in residual stocking levels between replications and between thinning methods for a given density level existed because a few trees marked for cutting were missed and some leave trees were accidentally pushed over by the "feller-buncher."

[1] A cooperative research effort between the Boise-Cascade Corporation and the Pacific Northwest Forest and Range Experiment Station.

[2] Site index based on curves in "Ecology and Silviculture of Western Larch Forests," by Wyman C. Schmidt, Raymond C. Shearer, and Arthur L. Roe, U.S. Department of Agriculture Tech. Bull., in preparation for publication.

[3] Mention of product name does not imply endorsement by the U.S. Department of Agriculture over other machines that can do the work.

Table 1--*Stand characteristics per acre of western larch before and after 1970 thinning and 5 years later*[1]

Density level	Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height[2]	Volume[3]	
						Total	Merchantable, including ingrowth
	Square feet		Feet	Inches	Feet	Cubic feet	Board feet
Before initial (1970) thinning:							
Thinned from above							
1 (lowest)	221.5	420	10.2	9.8	85.1	7,177	26,816
2	191.5	495	9.4	8.4	80.3	6,032	18,540
3	213.7	408	10.3	9.8	90.1	6,883	27,020
4 (highest)	202.0	513	9.2	8.5	82.0	6,285	18,045
Thinned from below							
1	211.0	490	9.4	8.9	95.3	6,892	24,555
2	205.5	557	8.8	8.2	91.8	6,688	20,898
3	221.5	596	8.5	8.3	93.7	7,192	19,479
4	226.0	525	9.1	8.9	92.4	7,402	26,446
After thinning:[4]							
From above							
1	50.6	133	18.1	8.4	85.1	1,647	2,816
2	93.8	257	13.0	8.2	80.3	2,906	5,687
3	126.0	231	13.7	10.0	90.1	4,091	13,990
4	153.0	400	10.4	8.4	82.0	4,670	10,054
From below							
1	48.9	58	27.4	12.4	94.8	1,686	8,331
2	87.7	114	19.5	11.9	91.8	2,974	13,503
3	131.8	196	14.9	11.1	93.7	4,448	16,790
4	169.0	219	14.1	11.9	92.0	5,801	24,440
1975:[4]							
Thinned from above							
1	50.4	111	19.8	9.1	88.3	1,668	4,309
2	99.2	239	13.5	8.7	84.0	3,105	7,273
3	132.9	220	14.1	10.5	94.5	4,346	15,880
4	158.2	378	10.7	8.8	86.0	4,876	13,260
Thinned from below							
1	55.5	58	27.4	13.3	99.1	1,925	10,005
2	96.5	114	19.5	12.5	95.1	3,312	16,141
3	141.4	196	14.9	11.5	96.9	4,775	19,732
4	183.6	219	14.1	12.4	96.4	6,274	28,440

[1]Based on plots without clearcut strips.
[2]Average height of trees measured with dendrometer (about 15 per plot).
[3]Total cubic-foot volume--entire stem, inside bark, all trees. Board-foot volume, International 1/4-inch rule--trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.
[4]Basal area, number of trees, and volume per acre after thinning and in 1975 should be reduced by 29 percent if clearcut strips are included in plot area.

Figure 1.--Aerial view of part of the thinned area showing alternating thinned and clearcut strips.

Diameters of all plot trees were measured to the nearest one-tenth inch (0.25 cm) in 1970 and 1974. In addition, about 15 trees covering the range of diameters were measured with an optical dendrometer in 1970 and 1974 to calculate an equation expressing volume of the entire stem inside bark as a function of diameter for each plot. The volume equations developed from the 1970 measurements were used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the period. Height growth was measured by dendrometer on trees chosen for volume equation measurements.

Because of the mechanized thinning equipment used in this stand, much of the total area was occupied by clearcut strips, resulting in a reduction in volume growth compared with a thinned area completely occupied by trees. Therefore, in this paper, growth per acre is presented in two ways: based on the 0.286-acre (0.116-ha) plot completely occupied by trees and based on a larger 0.4-acre (0.162-ha) plot that includes the clearcut strips.

Examination of basal area and volume growth data for the plot containing 22-percent basal area in fir revealed an unusually high growth rate because of the more rapid growth of the fir. Therefore, data from this plot were not used in the growth analyses.

RESULTS

Diameter Growth

Diameter growth per tree was greatest on the most heavily thinned plots for both thinning methods (table 2). The average growth in plots thinned from above declined from 0.1 inch (0.25 cm) per year at the lowest density level to 0.05 inch (0.13 cm) per year at the highest density. In plots thinned from below, growth slowed from 0.16 to 0.09 inch (0.41 to 0.23 cm) per year as stocking increased. Diameter growth in plots thinned from below was significantly greater ($P < 0.05$) than growth in plots thinned from above (fig. 2), and a significant ($P < 0.01$) linear relationship existed between diameter growth and residual basal area for both thinning methods. There was no significant interaction between thinning method and density levels.

Diameter growth of the 49 largest trees per acre (121/ha) was somewhat greater than growth of all trees (table 2), and differences were more apparent in plots thinned from above and at higher density levels because of more smaller, slower growing trees in these plots. Although there was a tendency for larger trees to grow slightly faster than smaller trees, there was little relationship between diameter and diameter growth during the 5 years. Regressions of diameter growth on initial diameter for each plot resulted in r^2 values ranging from 0.03 to 0.52. Many small trees had no measurable increment, but a few 6-inch (15-cm) trees grew as well as some 15-inch (38-cm) trees. On the other hand, not all large trees grew rapidly. One 22-inch (56-cm) tree and several 14- and 15-inch (36- and 38-cm) trees added no measurable growth.

As one might expect, thinning method had a considerable effect on the diameter distribution and stand structure of plots. Thinning changed the diameter of the average tree (tree of average basal area) as follows:

Thinning method and density level (Ft^2 per acre)	Change in average diameter (Inches)
Above:	
50	-1.4
90	-.2
130	0
170	-.1
Below:	
50	+3.5
90	+3.7
130	+2.8
170	+3.0

Table 2--*Periodic annual growth and mortality per acre of western larch after initial thinning at age 55*

Density level	All trees												49 largest trees--diameter growth[1]
	Residual basal area	Diameter growth[1]	Basal area growth			Total volume growth			Merchantable volume growth, including ingrowth			Board-foot ingrowth	
			Net	Mortality	Gross	Net	Mortality	Gross	Net	Mortality	Gross		
	Square feet	Inches	Square feet			Cubic feet			Board feet			Board feet	Percent	Inches
Based on area without clearcut strips:														
Thinned from above														
1 (lowest)	51	0.10	-0.04	1.12	1.08	4	34	38	299	0	299	225	75.2	0.12
2	94	.08	1.08	.85	1.93	40	25	65	317	0	317	163	51.4	.12
3	126	.08	1.38	1.12	2.50	51	37	88	378	132	510	202	39.6	.14
4 (highest)	153	.05	1.04	.91	1.95	41	24	65	641	0	641	456	71.2	.09
Thinned from below														
1	49	.16	1.32	0	1.32	48	0	48	335	0	335	33	9.8	.17
2	88	.12	1.76	0	1.76	68	0	68	528	0	528	109	20.6	.13
3	132	.08	1.92	0	1.92	65	0	65	588	0	588	278	47.2	.10
4	169	.09	2.92	0	2.92	95	0	95	800	0	800	248	31.0	.12
Based on area including clearcut strips:														
Thinned from above														
1	36	.10	-.03	.81	.78	3	24	27	213	0	213	161	75.6	.12
2	67	.08	.78	.61	1.39	29	18	47	227	0	227	116	49.8	.12
3	89	.08	.98	.80	1.78	36	26	62	268	94	362	143	39.6	.14
4	109	.05	.74	.65	1.39	29	18	47	458	0	458	326	71.2	.09
Thinned from below														
1	35	.16	.94	0	.94	34	0	34	239	0	239	24	10.0	.17
2	63	.12	1.25	0	1.25	48	0	48	377	0	377	78	20.7	.13
3	94	.08	1.36	0	1.36	47	0	47	420	0	420	198	47.1	.10
4	121	.09	2.07	0	2.07	68	0	68	571	0	571	177	31.0	.12

[1]Arithmetic diameter growth of trees living through the 5-year period.

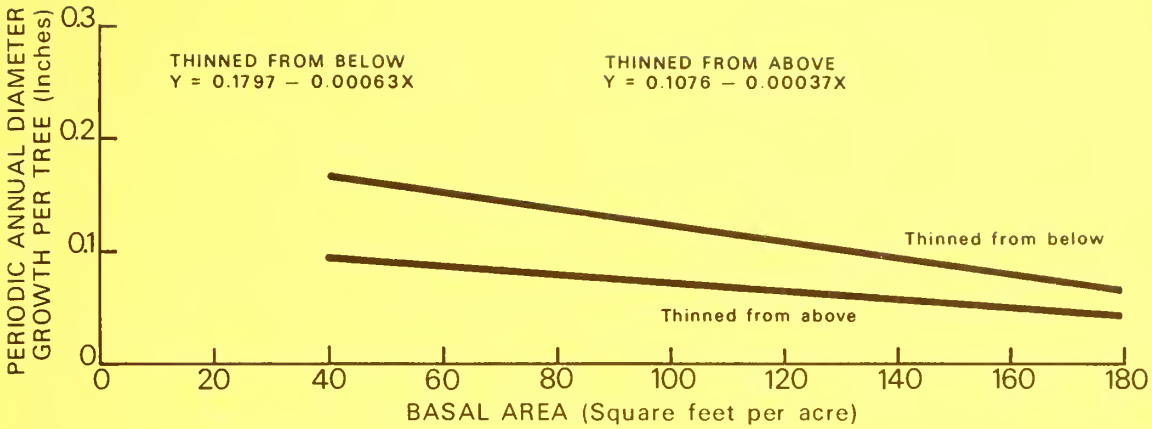

Figure 2.--Periodic annual diameter growth by density level and thinning method, 1970-75.

Diameter increment was much greater for firs and spruce than for larch. On the one plot containing 22-percent basal area in fir, fir grew 0.18 inch (0.46 cm) and larch 0.06 inch (0.15 cm) per year. Most of the fir in this plot were in the intermediate to suppressed crown classes before thinning. Because of their shade tolerance, however, they had relatively full crowns and thus were able to respond quickly to the increased growing space provided by thinning.

Height Growth

Height growth was insensitive to thinning method or changes in stand density (fig. 3). Only insignificant differences in growth occurred as stocking changed within a thinning method, and there was no significant growth difference between thinning methods. Increment ranged from 0.62 to 0.88 feet (0.19 to 0.27 m) per year in plots thinned from above and from 0.62 to 0.89 feet (0.19 to 0.27 m) per year in plots thinned from below.

As in the case of diameter growth, there was a poor relationship between height growth and height at time of thinning (r^2 values from 0.03 to 0.34).

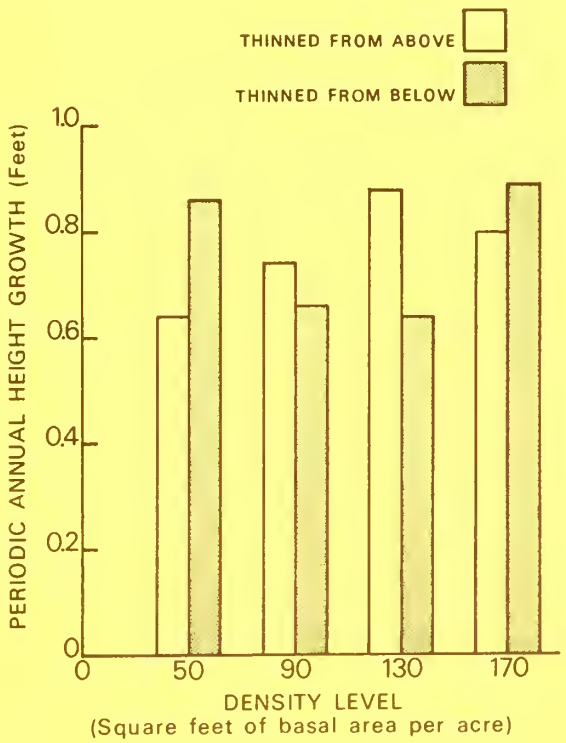

Figure 3.--Periodic annual height growth by density level and thinning method, 1970-75.

Mortality and Damage

All the mortality occurred in plots thinned from above. Of the 570 trees in these plots, 40 died; but there was no noticeable effect of density level on mortality. Death is attributed to either windthrow or shock following release. Most of the trees that died were in the intermediate and suppressed crown classes and thus had not developed sufficient windfirmness or large enough crowns to keep pace with the increased respiratory rate after release.

In addition to mortality losses, 53 study trees (all but 5 in the plots thinned from above) were leaning at angles estimated to be 10 to 35 degrees from the vertical as a result of wind or ice damage.

Basal Area Growth

Basal area increment showed an upward trend for both thinning methods as stocking increased (table 2). There was no significant difference in gross basal area growth between the two thinning methods. But because of the mortality in plots thinned from above, net basal area growth was significantly greater ($P < 0.05$) in plots thinned from below (fig. 4). The regressions of both gross and net basal area growth on stand density were linear ($P < 0.05$), and no significant interaction was found between thinning method and stand density.

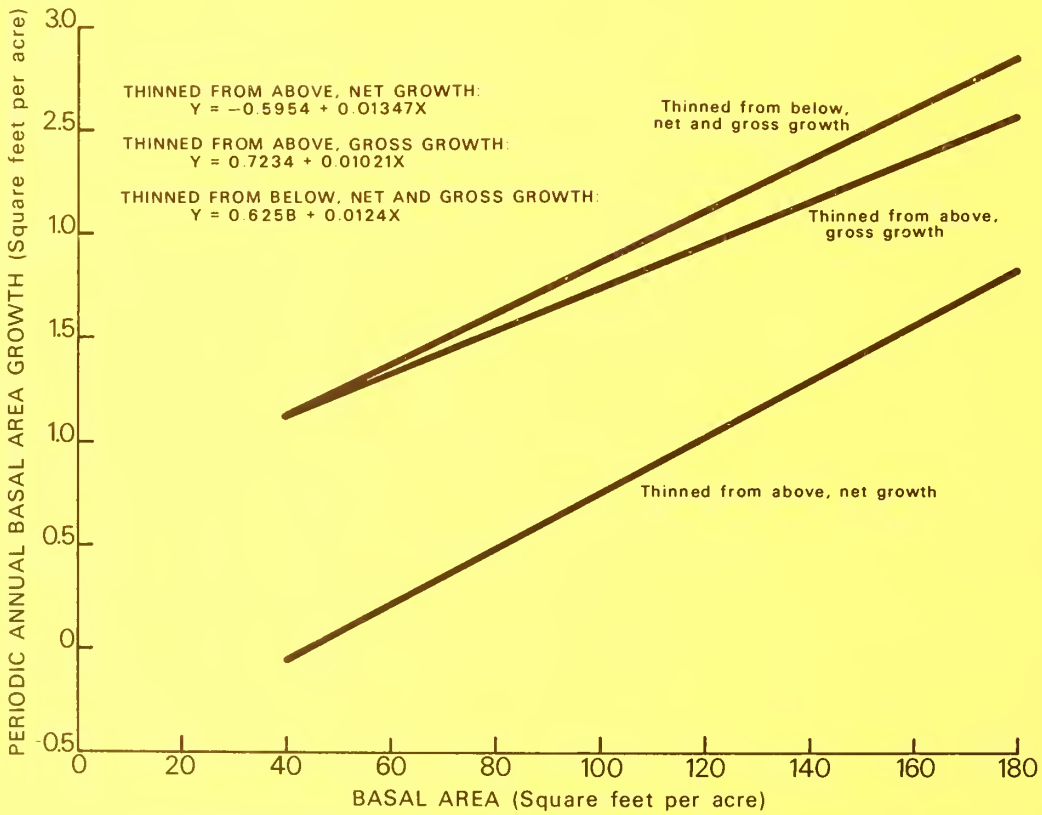

Figure 4.--Periodic annual basal area growth by density level and thinning method, 1970-75. Only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality.

Volume Growth

Cubic volume increment responded to changes in stand density in the same manner as basal area increment--growth increasing as density became greater. Comparison of cubic volume increment between the two thinning methods indicates that plots thinned from below grew significantly better than those thinned from above both in net ($P < 0.01$) and gross ($P < 0.05$) growth (fig. 5). Mortality caused a loss of from 37 to 89 percent of the gross cubic volume growth in plots thinned from above in contrast to no loss in plots thinned from below.

Analyses of both net and gross cubic volume growth in figure 5 indicated that the data do not depart significantly from linearity. However, over a greater range of stand densities, a curvilinear relationship is more likely since growth must necessarily be zero at zero stand density and will tend to level off and then decline as stocking increases above 180 ft^2 of basal area per acre (41 m^2/ha). Although volume increment is greater at high stand densities, the volume is distributed over a large number of trees, many of which are smaller and slow growing. Thinning serves to transfer growth to fewer faster growing trees in addition to utilizing potential mortality. For example, in plots thinned from below, 58 trees per acre (143/ha) at the low density level produced 51 percent of the cubic volume grown by 219 trees per acre (541/ha) at the high level; in plots thinned from above, gross growth on 133 trees per acre (329/ha) was 58 percent of that on 400 trees per acre (988/ha).

Net board-foot volume increment was impressive during the period, ranging from 299 to 641 board feet per acre annually on the plots thinned from above and from 335 to 800 board feet per acre per year on plots thinned from below (table 2). There was no loss of board-foot increment to mortality except for one 14-inch (36-cm) tree that blew down in level 3 (thinned from above); thus gross growth is essentially the same as net. One-tenth to three-fourths of the board-foot increment consisted of ingrowth which is the volume of trees periodically growing into measurable size.

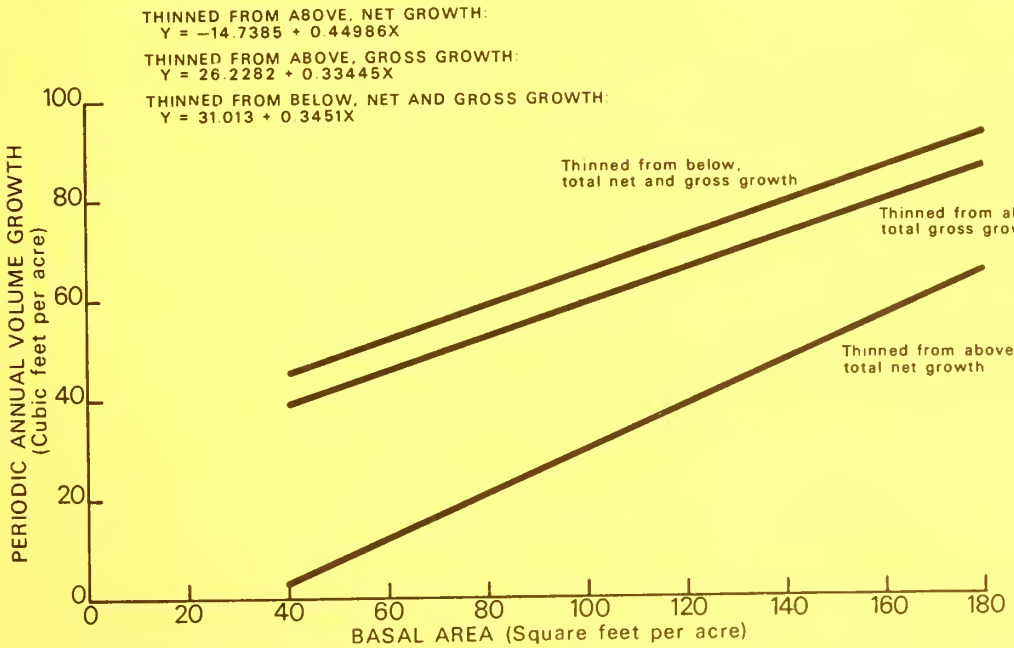

Figure 5.--Periodic annual cubic volume growth by density level and thinning method, 1970-75. Only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality.

Similar to cubic volume growth, net board-foot increment of plots thinned from below was significantly greater ($P < 0.05$) than net increment of plots thinned from above (fig. 6), and the difference between gross board-foot growth for the two thinning methods was almost significant at the 5-percent level. A significant ($P < 0.01$) linear relationship was found between board-foot growth and stocking level over the range of densities used.

Thinning this stand with the "feller-buncher" caused about 29 percent of the total area to be occupied by clearcut strips, with a corresponding 29-percent reduction in volume growth compared with a thinned area completely occupied by trees. This percentage reduction in volume growth is equal to that proportion of the area not occupied by trees because of the 29-percent difference in the per-acre conversion factors used for the two plot sizes. Because of root and crown expansion into the clearcut strips as the stand grows older, the actual reduction in volume growth on an area basis should be less than the 29 percent calculated. The growth and mortality data on an area which includes the clearcut strips are shown in the bottom half of table 2.

DISCUSSION

It is not possible to generalize in regard to thinning prescriptions for western larch stands from isolated studies. However, after only 5 years of growth, some trends seem apparent. Thinning from above does not appear to be a sound silvicultural practice in previously unmanaged larch stands of this age. Because of the shade intolerance of larch, crowns of the smaller trees in the stand are reduced in size and thus are unable to immediately use the increased growing space. The reduction in net volume growth because of mortality of smaller trees is another disadvantage of thinning from above. Additional mortality of trees already damaged by wind and snow could result in stocking levels too low for efficient site utilization and in continued low growth rates.

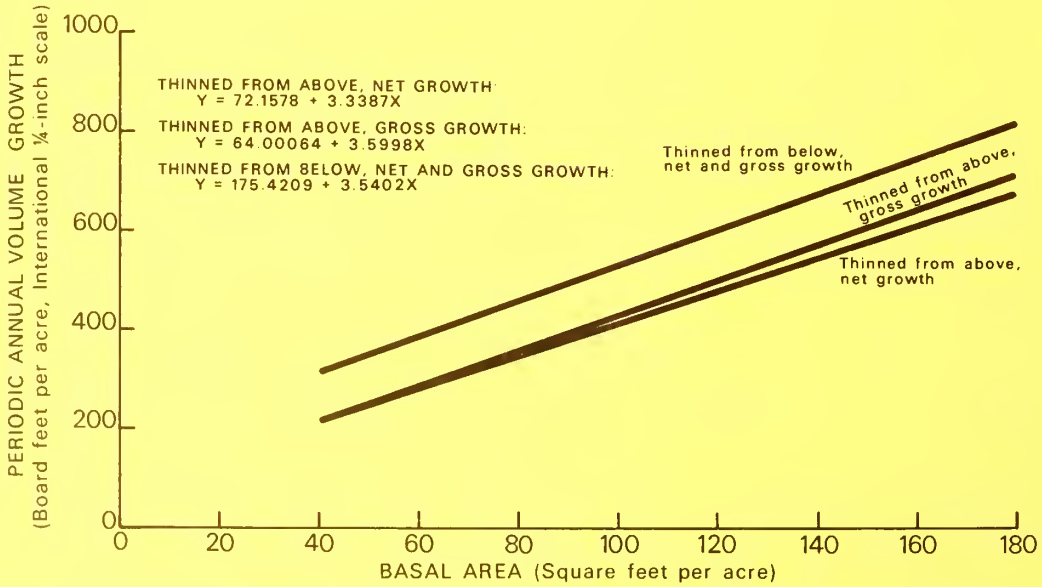

Figure 6.--Periodic annual board-foot (International 1/4-inch rule) volume growth by density level and thinning method, 1970-75. Only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality.

For thinning from below in stands such as this one, what is the proper residual stocking level? Obviously, there is no single best stand density; but the answer depends on the objectives of thinning in terms of timber management as well as the relative importance to the land manager of other uses of the forest such as range, wildlife, water yields, or recreation. Some objectives of thinning for timber management purposes are: (1) to stimulate diameter growth rate of residual trees so merchantable products may be harvested sooner and rotations shortened, (2) to salvage volume that otherwise would be lost through mortality, and (3) to obtain the maximum volume growth per acre that is consistent with other objectives.

In this study, from 70 to 100 percent of the trees left on the plots thinned from below were 10-inch (25-cm) d.b.h. or larger. In such a stand, near-maximum diameter growth to reach merchantability limits quickly is no longer the prime objective. Rather, thinning goals now are to utilize mortality, to maintain good volume growth per acre, or to shorten rotations. If the management objective is to obtain high volume growth per acre, then a light thinning from below is indicated to utilize anticipated mortality. If, on the other hand, the aim is to shorten the rotation--with a sacrifice of some volume growth--a heavier thinning is suggested.

Although 55 years old, about 63 percent of the trees in this stand were less than 10-inch (25-cm) d.b.h. before thinning. Obviously, a thinning program begun at an earlier age would have transferred the rapid growth during the sapling and pole stages to crop trees. All trees would now be merchantable with large crowns and stem form adequate to resist windthrow and snow or ice damage. For example, in a 33-year-old larch stand in eastern Oregon (site index 80) (Seidel 1971), volume growth after thinning to 50 ft^2 per acre (11.5 m^2/ha) was 86 ft^3 per acre (6 m^3/ha) per year compared with an annual growth rate in this 55-year-old stand of 48 ft^3 per acre (3.4 m^3/ha) when thinned from below to the same density level.

Because of its shade intolerance and the tendency of many natural stands to be heavily overstocked, larch is a species in which early thinning should have high priority. Studies in Montana show that diameter and height growth of unthinned stands were significantly decreased by overstocking as early as 9 years of age (Schmidt 1966). Although mortality reduces stocking as stands grow older, many spindly trees with small crowns survive. These trees show little or no growth response to thinning and are most susceptible to wind damage.

LITERATURE CITED

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, p. 195-196. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Illingworth, K.
1964. Crop-tree thinning of western larch. B.C. For. Serv. Res. Rev. 1964:52.

Roe, Arthur L., and Wyman C. Schmidt.
1965. Thinning western larch. USDA For. Serv. Res. Pap. INT-16, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Schmidt, Wyman C.
1966. Growth opportunities for young western larch. USDA For. Serv. Res. Note INT-50. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Seidel, K. W.
1971. Growth of young even-aged western larch stands after thinning in eastern Oregon. USDA For. Serv. Res. Note PNW-165, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Thompson, C. F.
1969. Crop-tree thinning of western larch. B.C. For. Serv. Res. Rev. 1969:94.

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USING MOTION PICTURES FOR DATA COLLECTION ON PRESCRIBED BURNING EXPERIMENTS

by

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ABSTRACT

A simple, inexpensive, and relatively accurate photographic method for data collection is described. Objects of interest are triangulated from films taken simultaneously at two camera positions. Accumulated synchronization and measurement errors amounted to 0.2-0.5 m. The method appears adequate for most applications on field experiments of prescribed burning.

Keywords: *Photo interpretation, fire use.*

Most fire researchers use cameras on prescribed burns and experimental fires. They also collect time-lapse motion pictures of many of these fires. However, while some objective information might be taken from such photographs, the full potential of photography as a data collection system is apparently overlooked in many experiments.

Fire phenomena are often highly transitory but produce visible effects which can be captured on film for later reconstruction and analysis. Fritschen et al.[1] used photographs to study flame structure, speed, and approximate temperature. Palmer[2] used photographs to study smoke plume volumes from fires of different sizes and intensities. We were interested in smoke plume velocities and volume flows resulting from small test fires and found that photography was, by far, the simplest and cheapest option available to us.

Our method, described below, is only one possibility for incorporating motion pictures into a data collection system. Other studies or objectives might require different techniques. We offer this discussion as one example of photographic data collection which could be applied to similar situations.

Application of Photography to the Bend, Oregon, Experiments

A number of separate experiments were conducted using twenty-four 0.01-acre (0.004-ha) fuelbeds burned near Bend, Oregon. Our purpose was to investigate the amounts of certain smoke constituents produced (particulate matter, hydrocarbon gases, etc.) as a function of fire intensity and treatment of fuels with flame retardant chemicals. We sampled concentrations of these constituents at various points within the plume; but without some idea of plume volume flow, we could not relate these concentrations to the total amounts of these constituents produced by the fires. Our experiments were designed to obtain estimates of these plume volume flows from motion picture photography.

The fuelbeds were 21 feet (6.4 m) square and built on cleared, level ground. The cameras were located primarily on the basis of distance from the fuelbed and lighting. We were interested in the lowest portion of the smoke plumes, so the camera positions were never more than 200 feet (61 m) from the fuelbed. At this distance, the plume occupied the center of the field of view. Under these conditions, the methods described below were sufficiently accurate for our purposes. However, they may not be appropriate if cameras are located at greater distances, differing elevations, or where measurements are made near the edges of the field of view.

We estimated the cross-sectional area of the plume by determining its width at a fixed height from two camera views and assuming an elliptical cross section. We then estimated volume flow from this cross-sectional area and the plume velocity, which we calculated by tracking either individual smoke puffs or neutral-buoyancy balloons entrained in the plume. The procedures used to locate the cameras and to make the calculations are described below.

Procedure for Locating Camera Positions

1. Locate two cameras at some convenient distance apart so that all activities of interest occur within the field of view of both cameras. (The lines of sight of the two cameras should intersect at some well-marked reference point.) We

[1]Fritschen, Leo, Harley Bovee, Konrad Buettner, and others. 1970. Slash fire atmospheric pollution. USDA Forest Service Research Paper PNW-97, 42 p. Pacific Northwest Forest & Range Experiment Station, Portland, Oreg. 1970.

[2]Personal communication with Thomas Y. Palmer, USDA Forest Service, Pacific Southwest Forest & Range Experiment Station, Riverside, Calif.

used two 16-mm movie cameras at right angles to and 55 m from the center of the slash pile to be observed.

2. Measure the distance from each camera film plane to the reference point (fig. 1, d_1 and d_2). Our reference point was a 12-m vertical steel tower marked with alternating 1.5-m green and white stripes.

3. Measure the distance between the two cameras (fig. 1, d_3).

4. Finally, measure the distance (d_r) from one of the cameras to some object of known length (R) in the plane perpendicular to the line of sight, which is visible in the field of view of that camera. We used 1.5-m stripes on the steel tower for (R), thus eliminating a separate set of measurements.

Calculations are much easier if all measurements are recorded in the same units. This includes measurements made from the projected film images. Focal lengths of the two camera lenses should ideally be the same, as should lenses used for projecting the film during measurement.

Photograph pairs must be made at or sufficiently near the same instant in time for purposes of the experiment. A pair of solenoid shutter actuators, both triggered by the same pulse, is easy to install if the electrical connections are physically practical.[3] Otherwise, a film speed of 24 frames

[3]Radio-controlled synchronization has been developed and used for this purpose by researchers at the Northern Forest Fire Laboratory (Rod Norum, personal communication).

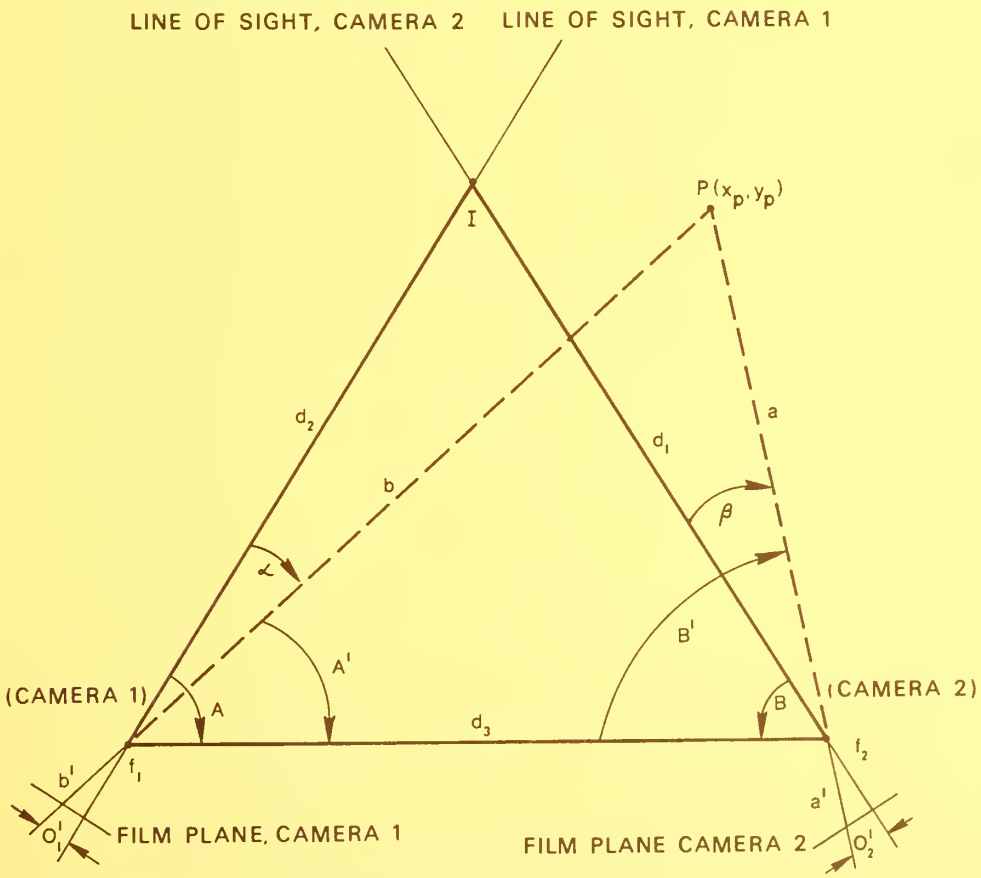

Figure 1.--Determination of spatial coordinates of point (X_p, Y_p) by triangulation from two camera views.

per second and a time marker visible to both cameras are adequate for many purposes. The error caused by inexact synchronization depends on both the frame rate and the velocity of the object of interest across the planes of view of the two cameras. In our work, we detonated about 3 ounces of flash powder which gave a flash usually visible in only one or sometimes two frames of each camera.

Measurements From Film Images

All distances are measured from the image of a point of interest (P') to the image of the fixed reference point (I', fig. 2). The horizontal and vertical components of these distances in each camera view are termed offsets and are identified by subscript according to which camera they are measured in (i.e., o_1 and z_1 are horizontal and vertical offsets, respectively, in a film frame from camera 1). Offset measurements are rapid and easy if the films are projected onto a horizontal rearview surface. We built a special table for this work beneath which we mounted two stop-frame projectors aimed vertically at the table surface (fig. 3). The viewing surface was

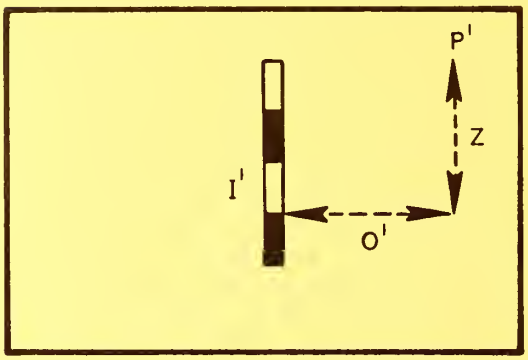

Figure 2.--Film image measurements. Offset from I' consists of horizontal (x, y) component and vertical (z) component. Film images are identified by prime marks (P' is the photo image of object P in field).

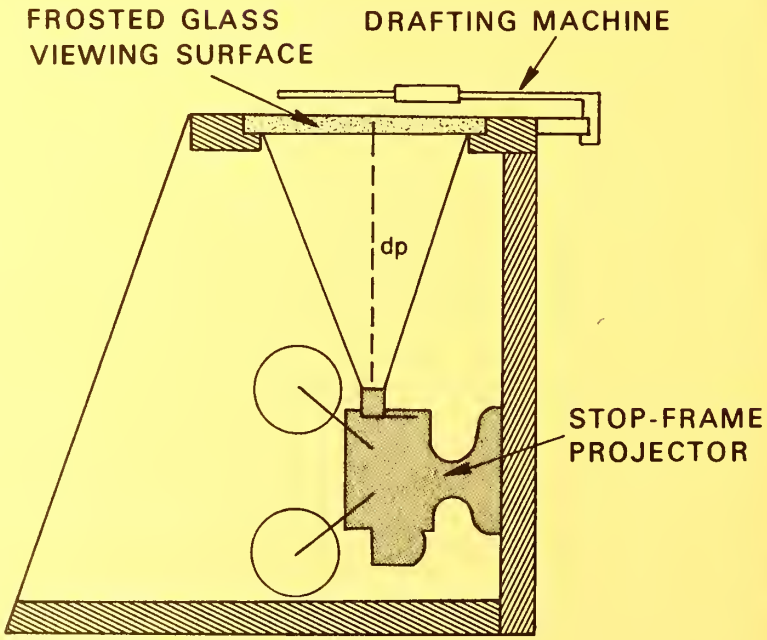

Figure 3.--Table used for measuring offsets from film images. Distance dp *is the distance from projector film plane to viewing surface.*

frosted glass and supported a drafting machine. Thus, both camera views of an event could be analyzed at one time. Digitizing equipment and motion analyzers are also well suited to this work.

A sign convention is necessary so that the measurements place the point in the proper quadrant. With this convention, horizontal offsets are given positive values if their position is to the right of the reference point in the projected image.

The vertical distance from the reference point to the object of interest (Z) is measured above or below the level line of sight from the camera positions to the reference point. If the object is above the reference point, Z is given a positive value. In our work, the cameras were mounted 1.5 m above flat ground, so the origin for vertical coordinates was a 1.5-m mark on the reference tower. Camera tilt will introduce some error but is not serious for most purposes when the tilt is less than 5°.

Determining the Coordinates of a Point From the Film Images

With the distances measured at the site, the triangle ABI (fig. 1) formed by the two camera positions and the reference point can be solved for angles A, B, and I by the law of cosines and the law of sines.

$$I = \cos^{-1} \frac{d_1^2 + d_2^2 - d_3^2}{2 d_1 d_2}$$

$$A = \sin^{-1} \frac{d_1}{d_3} \sin I$$

$$B = \sin^{-1} \frac{d_2}{d_3} \sin I$$

Converting film-image measurements to on-the-ground distances requires a proportionality constant for the camera-projector setup. This constant (f) is determined from the known reference length (R) visible in the film, the length of R's film image (R'), and the distance from R to the camera (d_r).[4]

$$f = \frac{R'}{R} \cdot d_r$$

For any point P lying within the field of view of both cameras, the new triangle ABP can be solved using the measured offsets o'_1 and o'_2 and the triangle ABI (fig. 1).

$$A' = A - \alpha \quad \text{and} \quad B' = B + \beta$$

where

$$\alpha = \tan^{-1} \frac{o'_1}{f_1} \quad \text{and} \quad \beta = \tan^{-1} \frac{o'_2}{f_2}$$

then

$$b = d_3 \frac{\sin B'}{\sin (A' + B')} \quad \text{and}$$

$$a = d_3 \frac{\sin A'}{\sin (A' + B')}$$

The horizontal location of point P can now be established by imposing a coordinate system upon ABP such that the coordinates of points A and B are $(0, 0)$ and $(d_3, 0)$, respectively. The coordinates of point P are then (x_p, y_p), where

$$x_p = b \cos A' = d_3 - a \cos B'$$

$$y_p = b \sin A' = a \sin B'$$

The vertical coordinate of point P is found from vertical offset z_i measured in either camera view.

$$Z_p = \frac{b}{b'} \cdot z_1 = \frac{a}{a'} \cdot z_2$$

where

$$b' = \frac{f_1}{\cos \alpha} \quad \text{and} \quad a' = \frac{f_2}{\cos \beta}$$

[4] If the focal lengths of the camera lens (f_c) and the projection lens (f_p) and the distance from projector film plane to viewing surface (d_p) are known, f can also be found from:

$$f = \frac{d_p}{f_p} \cdot f_c .$$

Tracking Moving Objects From Films

The track of a moving object during a period of observation is reconstructed from the coordinates computed from successive film-frame pairs. Speed or velocity of such an object can then be determined by computing the distance traveled by the object between any two pairs of frames and dividing by the elapsed time between frames. For motion picture cameras, elapsed time in seconds (T) equals the difference of the frame numbers of the two pairs used for measurement (n), times the reciprocal of the frame rate (r, in frames per second), or $T = n/r$ seconds.

Accuracy of the Method

Given sufficiently sophisticated equipment and patient attention to detail, almost any photographic method is capable of a high degree of accuracy. However, for highly accurate work, there are more suitable methods. This method is most useful for order-of-magnitude comparisons between observed and predicted phenomena.

The method as here described is subject to three main sources of error:

(1) Errors in measuring the camera-reference and camera-camera distances.

(2) Errors in measuring offsets from the projected film images.

(3) Synchronization errors between the two camera shutters.

Of these three sources, the last is the most difficult to control.

We controlled differences in frame rates between the two cameras with a battery-operated motor drive on each camera. With these motor drives and a suitable visual time marker, the maximum synchronization error should be less than 21.5 ms at 24 frames per second. Many different types of visual time markers can be devised. However, the flash and smoke of detonating flash powder is easy to spot in the films and guarantees locating those two film frames nearest each other in time.

When we know the maximum error in time, the corresponding error in position depends on the speed of the object observed and its path in relation to the plane of view of the camera. Positional errors of objects moving at speeds less than 10 meters per second relative to the plane of view amount to less than 0.2 m and are acceptable for reconstructing most trajectories within a smoke plume.

Errors from the second source occur during offset measurements. Some error is introduced if the axis of the projector lens (fig. 3) is not perpendicular to the viewing surface. Careful preparation of the projection and measuring equipment will minimize this source of error.

Additional errors are introduced as part of the measurements themselves. Even when the objects being measured are easily recognizable, the edges of the measured objects in the projected film images are not precise. Any error in locating these edges results in an error in on-the-ground coordinate locations. In our work, we were usually able to identify the edges of a white 1-m balloon on the projected image with an uncertainty of about 1 mm for a projector arrangement with an f of about 0.5. This magnitude of uncertainty yielded an on-the-ground error of about 10 cm at a distance of 55 m. Accuracy decreases rapidly when measuring objects whose edges are indistinct, such as puffs of smoke. We found it impractical to track individual smoke puffs in the films.

Errors from the final source arise in measuring camera-to-reference and camera-to-camera distances. Errors of a magnitude achievable with ordinary chaining techniques will produce an insignificant error in computed coordinates. However, we recommend that distance d_Z be measured rather than turning angle A with anything less accurate than a surveyor's transit.

(Solving a triangle for the length of a side to three significant figures requires angles measured to the nearest 10 minutes.) Accumulated errors in either alinement or distances have the effect of translating the coordinate system and thus lengthening or foreshortening all computed distances. These accumulated errors increase as distance from the camera points to the object increases and are usually most serious at extremes of the field of view.

Application of the Method

Using this method, we measured smoke plume velocities above a simulated slash fire, as well as estimating the volume flow rates of gases out of the fire. Figure 4 shows the results of this measurement at three periods during one fire.

We found that the spatial locations of objects could be determined within 0.2 to 0.5 m of their true positions. This accuracy was achieved without elaborate equipment or great expense in either time or money. The results were quite adequate for our purposes and would seem equally adequate for many applications involved in field studies of prescribed burning.

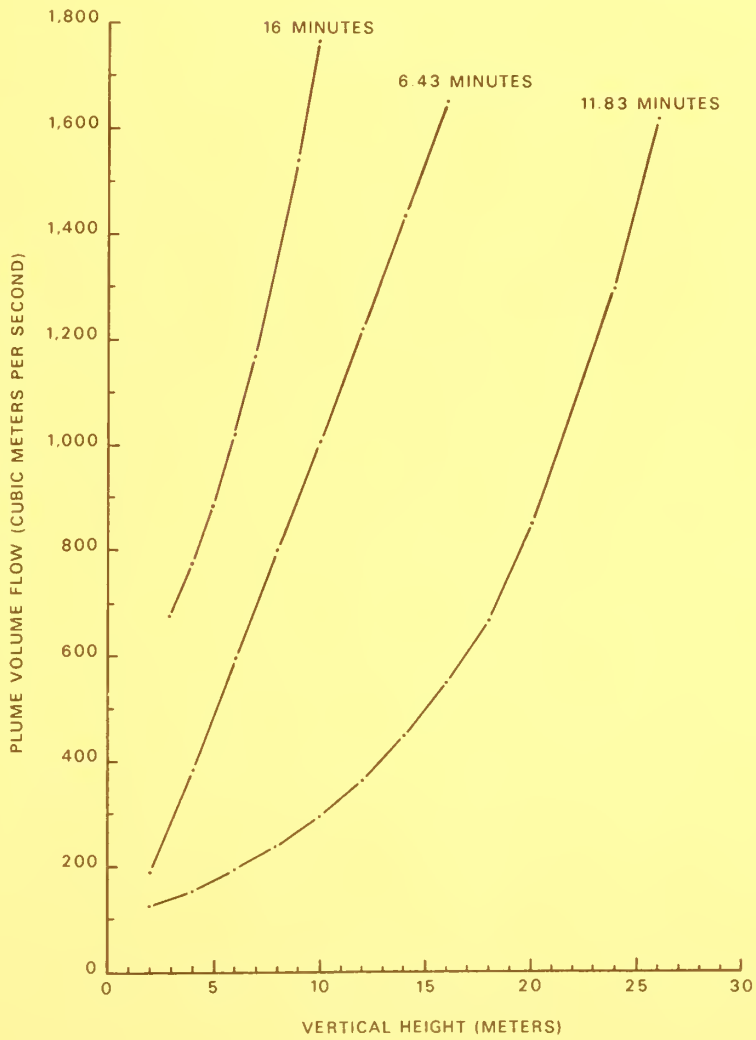

Figure 4.--Plume volume flow as estimated from speed of neutral buoyancy balloons and dimensions of smoke plume.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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GRAFT INCOMPATIBILITY IN *PINUS CONTORTA*

by

Donald L. Copes, *Principal Plant Geneticist*

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ABSTRACT

The characteristic symptom of incompatibility in 2- and 3-year-old lodgepole pine grafts was recessed union area that resulted from the unequal growth of adjacent union and nonunion xylem cambia. Xylem growth in union areas stopped prematurely or grew at an abnormally slow rate during the summerwood period, while scion and stock cambia on both sides of the union zones grew normally. Union zones were sunken below the level of surrounding xylem cells. New xylem growth by union tissues the following spring appeared to be normal, but again growth terminated abnormally early or was slowed during the summerwood period, and even deeper recessed areas resulted. Finally, compression girdles of necrotic cells formed within recessed bark areas. The presence of chlorotic needles and scion overgrowths proved to be accurate indicators of incompatibility and can be used as criteria to rogue problem grafts from lodgepole pine seed orchards. Abnormally short needles may also be a symptom of incompatibility. Compatible grafts had normal growth in both union and nonunion tissues, so no recessed areas or external distress symptoms were seen.

Keywords: Grafting, lodgepole pine, *Pinus contorta*, vegetative propagation (nursery).

INTRODUCTION

Little grafting of lodgepole pine (*Pinus contorta* Dougl.) was done in the United States until Weyerhaeuser Company started a grafting program in 1972 for a seed orchard near Klamath Falls, Oregon. They have made several thousand grafts since 1972; and 2 to 3 years after grafting, approximately 10 percent of the grafts exhibited external symptoms of incompatibility. A similar incidence of incompatibility was found in lodgepole pine grafts made in New Zealand.[1/] The most characteristic symptoms of incompatibility in both the Weyerhaeuser and New Zealand grafts were scion overgrowths at the union and chlorotic needles. Weyerhaeuser personnel recognized the problem as a potential hindrance to their tree improvement program and volunteered some of their graft unions for study. This paper presents the results of an anatomical examination of those 2- to 3-year-old *Pinus contorta* grafts.

MATERIALS AND METHODS

Grafting was done by Weyerhaeuser Company seed orchard personnel in the spring of 1972 and 1973. Top-cleft grafts were made on native seedlings found growing near selected plus-trees. It is likely that some stock trees were siblings of the scion clones grafted upon them. Immediately after grafting, the grafted trees were dug and put into 4- to 7-gallon containers, then hauled to the seed orchard site where they were kept in the containers for the next 2 to 3 years. A regular water and fertilizer schedule was followed.

Needle chlorosis, reduced needle elongation, and scion overgrowth at the graft union appeared on a number of the grafts 2 to 3 years after grafting. In 1974 Weyerhaeuser personnel collected a sample of 40 graft unions that appeared to be healthy or compatible and others that appeared to be incompatible. Their selection was based solely on the previously mentioned union and needle chlorosis symptoms. Collected unions were stored in 50-percent alcohol immediately after cutting from stocks. The unions were cut into cross sections 25 µm thick with a sliding microtome, stained with safranin-O and fast green, and made into permanent microscope slides.[2/]

RESULTS AND DISCUSSION

Comparison of the phenotypically selected incompatible grafts with healthy grafts showed incompatible grafts to have recessed xylem areas where stock and scion xylem tissues were contiguous (figs. 1-3). Healthy grafts showed little or no recessed areas in union zones

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1/ Thulin, I. J. 1975. Personal communication dated May 1, 1975. For. Res. Inst., N. Z. For. Serv., Rotorua, N. Z.

2/ Copes, Donald L. 1967. A simple method for detecting incompatibility in 2-year-old grafts of Douglas-fir. U.S. Dep. Agric. For. Serv. Res. Note PNW-70, 8 p. U.S. Dep. Agric. For. Serv., Pac. Northwest For.and Range Exp. Stn., Portland Oreg.

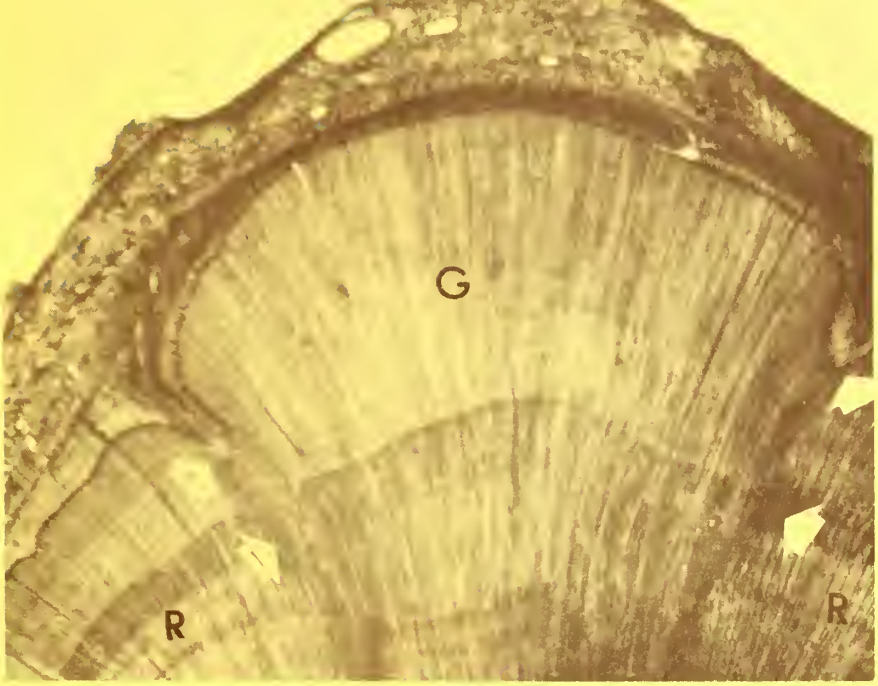

Figure 1.--A typical incompatible lodgepole pine graft union is pictured in cross section at 15X magnification. Recessed union areas are identified at the arrows (arrow 1 = 1973 recessed xylem and arrow 2 = 1974 recessed xylem). Recessed areas were deeper at the end of the third year than at the end of the second year. (G, scion; R, rootstock.)

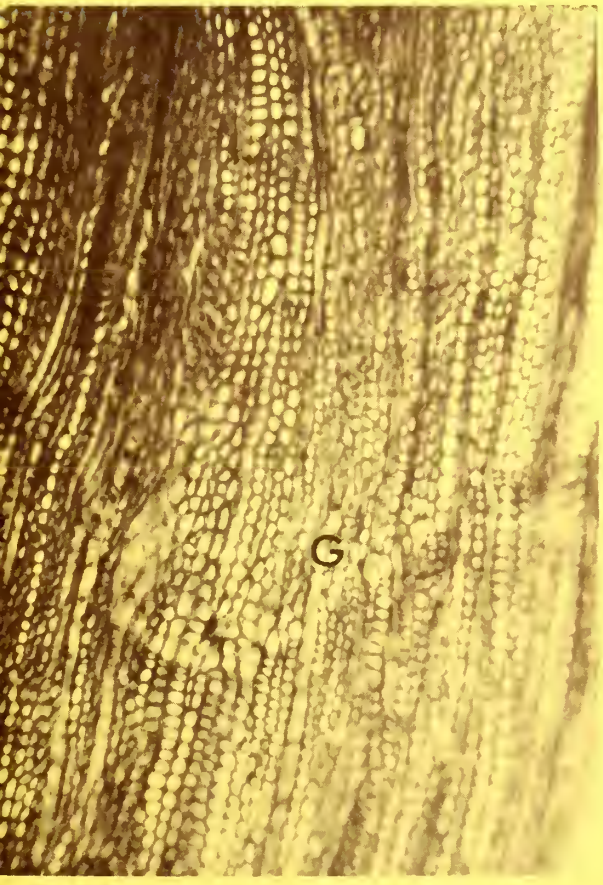

Figure 2.--The recessed union area No. 1 from figure 1 is pictured in cross section at 100X magnification. This sunken area formed the second summer after grafting and was the first indication that the graft was incompatible. No abnormal cell types preceded the first growth stoppage, and little change in cell arrangement or type occurred when growth resumed the following spring. (G, scion; R, rootstock.)

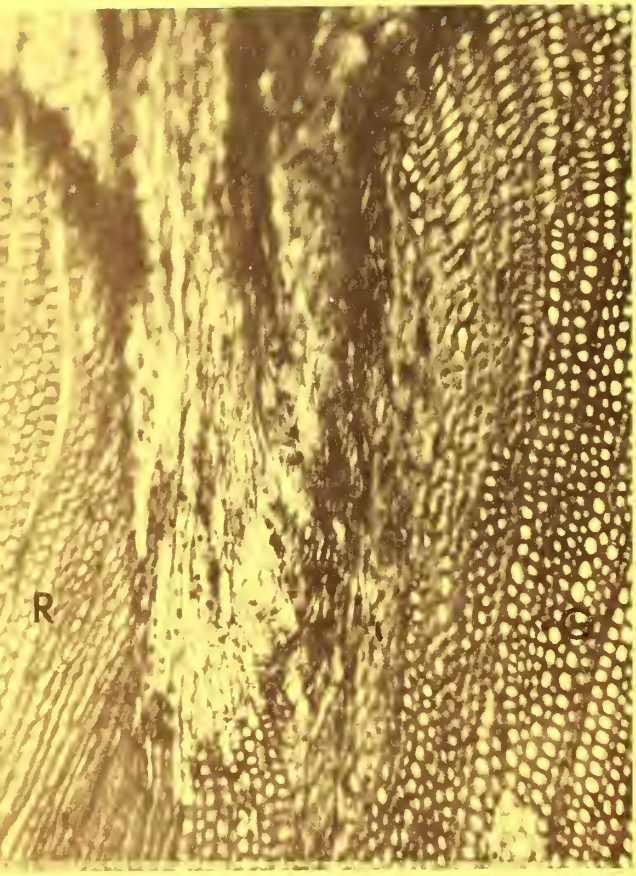

Figure 3.--Sunken xylem and bark area No. 2 from figure 1 is pictured in cross section at 100X magnification. This abnormality occurred in the same union zone as that in figure 2, but at the end of the third year rather than the second year. The depth of the recessed area was much greater at the end of the third year than at the end of the second year. Compression of bark cells within the sunken areas had begun. (G, scion; R, rootstock.)

(figs. 4-6). Depth of the recessed areas in incompatibles varied within the two to four union zones where stock and scion cells were contiguous. Recessed areas were usually deeper in 3-year-old grafts than in the 2-year-old grafts.

The last formed tracheids at the bottom of each recessed area indicated that xylem formation ceased or slowed down after one-half to three-quarters of each year's summerwood increment had formed. No wound cells or other signs of trauma were evident before the first growth stoppage or slow down (fig. 3). Xylem initials in union zones formed fewer xylem cells than did stock and scion cells adjacent to the union areas where normal growth continued. The unequal growth between adjacent cells resulted in characteristic sunken or recessed areas in the annual growth rings seen in cross sections (fig. 1).

Incompatible grafts were not noticeably different from compatible grafts through the first year. Some recessed xylem areas were found in the first annual ring of 2- and 3-year-old grafts, but ordinary grafting imperfections, such as slight errors in positioning of the cut stock and scion cambial surfaces at time of grafting, made it difficult to differentiate between incompatible and technique-caused deformities at the end of the first year. Technique-caused irregularities were

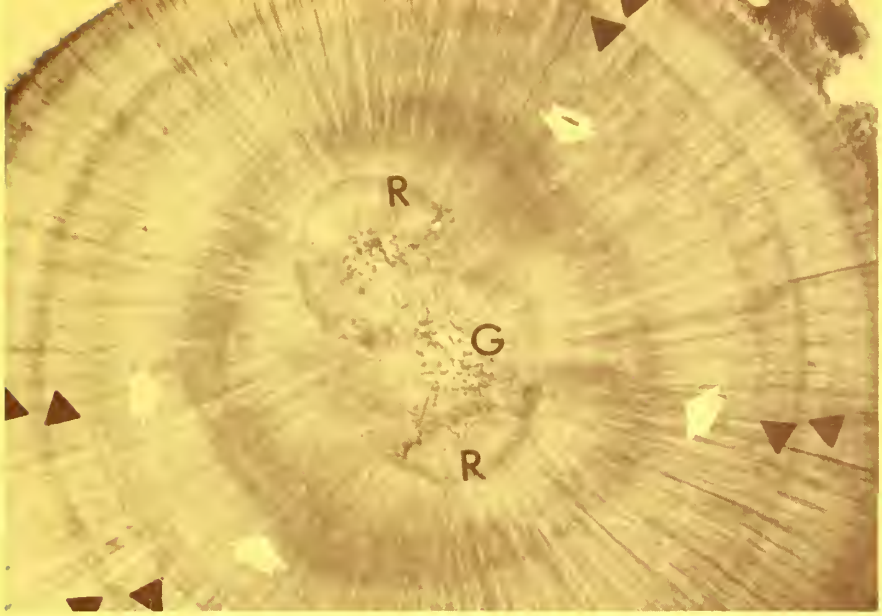

Figure 4.--A compatible lodgepole pine graft is shown in cross section at 15X magnification. No recessed areas were visible in any of the four union zones. Union zones indicated at the arrows (white = 1972, black = 1973 and 1974). Slight irregularities in the annual ring occurred at the end of the first year in several union zones; but normal growth the second and third years compensated for the sunken areas, so a round xylem cylinder was formed. (G, scion; R, rootstock.)

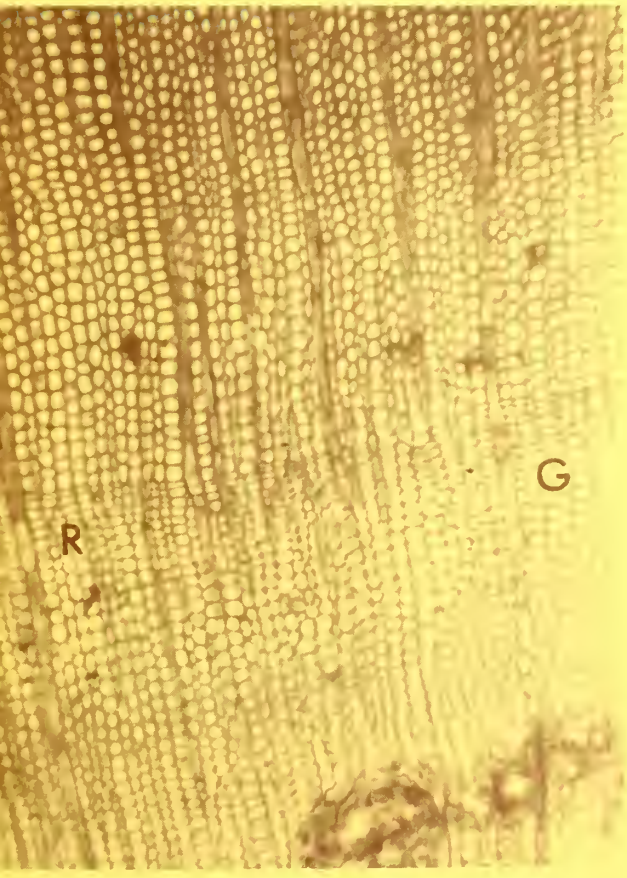

Figure 5.--Union zone No. 1 from figure 4 is shown in cross section at 100X magnification. No signs of abnormal growth were seen. Cell types before and after the annual ring were normal. (G, scion; R, rootstock.)

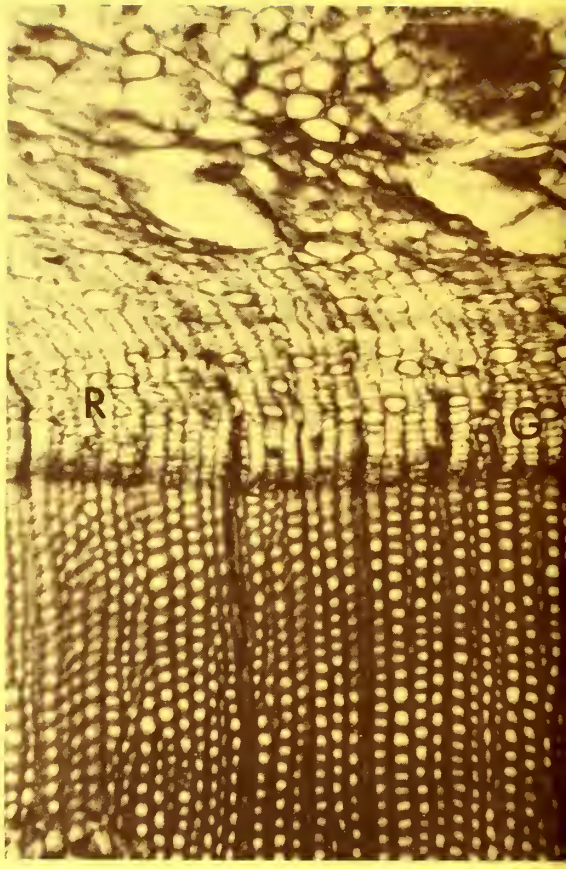

Figure 6.--The xylem and bark areas of union zone No. 1 of figure 4 are shown in cross section at 100X magnification. No sign of a recessed area was visible 3 years after grafting. The cambia of stock and scion appeared normal, and there were no symptoms of graft incompatibility. (G, scion; R, rootstock.)

reduced or eliminated during the second year. At that time the cambial zone was much more circular when seen in cross section and detection of recessed union areas was much easier. Detection after 3 years was even easier than at the end of the second year because deeper invaginations had formed (figs. 2 and 3).

Recessed areas of graft unions were not visible externally (fig. 1). Phloem growth may have been stimulated where xylem growth was abnormal since the bark areas of many union areas had a profusion of phloem cells in radial files. Increased phloem growth physically compensated for the lack of xylem cells in recessed areas.

Little necrosis was observed in bark areas of 2-year-old incompatible grafts, but a number of 3-year-old grafts had isolated islands of necrotic phloem and cortex. Necrosis appeared to be preceded by cell dilation and was restricted to union tissues (fig. 7). Cell rejection in lodgepole pine was very different from Douglas-fir grafts, where a possible hypersensitive type of reaction caused extensive suberization and necrosis of contiguous stock and scion cells.[3/] Necrosis in

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[3/] Copes, Donald L. 1970. Initiation and development of graft incompatibility symptoms in Douglas-fir. Silvae Genet. 19(2-3): 101-107.

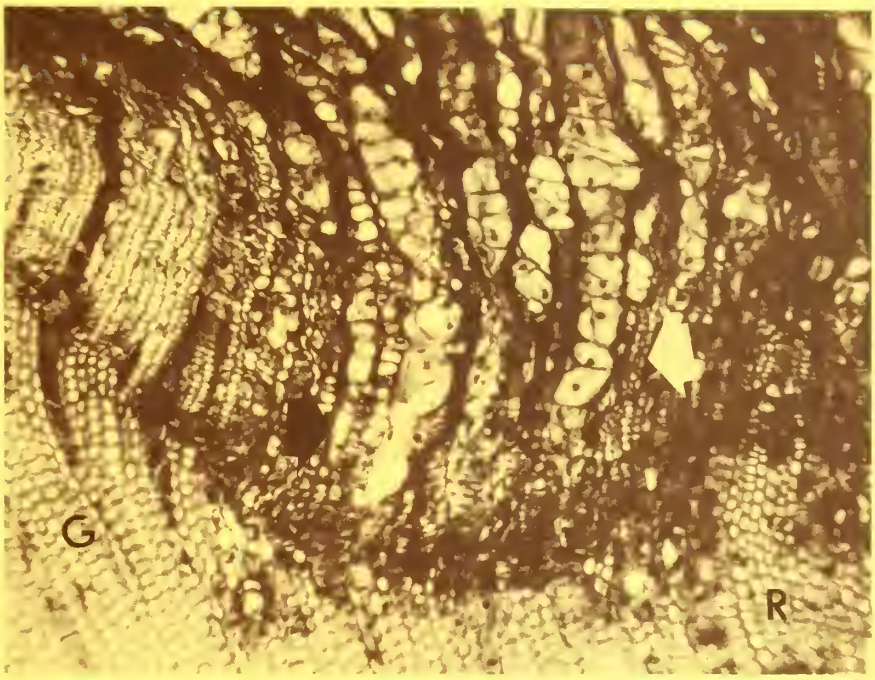

Figure 7.--Dilated ray cells in bark tissues of an invaginated union zone are shown in cross section at 100X magnification. The union cells were larger than similar cells in nonunion locations. Greatly enlarged cells in unions were necrotic in many 3-year-old grafts. (G, scion; R, root-stock.)

lodgepole pine grafts appeared to be more of an indirect effect, resulting from cell crowding or compression in recessed areas rather than from between-cell interactions.

Xylem growth began each spring without the formation of large wound areas that characterize incompatible Douglas-fir grafts (see footnote 3). No abnormal cells were formed the next spring, so the cambia in the union zones had merely become dormant during the summerwood period and had not been physically changed. When the factors limiting growth were removed or reduced the following spring, the union areas grew normally until the limiting conditions recurred. Recurrence of the same phenomenon compounded the problem caused by the previous year's reduced growth and even deeper recesses formed (figs. 2 and 3). Bark and cambial areas within deeply recessed areas became compressed and isolated. Necrosis of cells in compressed areas resulted in a girdle zone of dead tissue that separated stock and scion. Girdled trees had reduced needle growth, chlorotic needles, and scion overgrowths and would have died within several years if they had not been sacrificed for study.

The recurrence of premature growth termination the third year was often preceded by the proliferation of ray and axial parenchyma in recessed xylem areas. Axial parenchyma cells, resembling epithelial cells which normally surround resin canals, were present in great numbers but with no apparent organization (fig. 8).

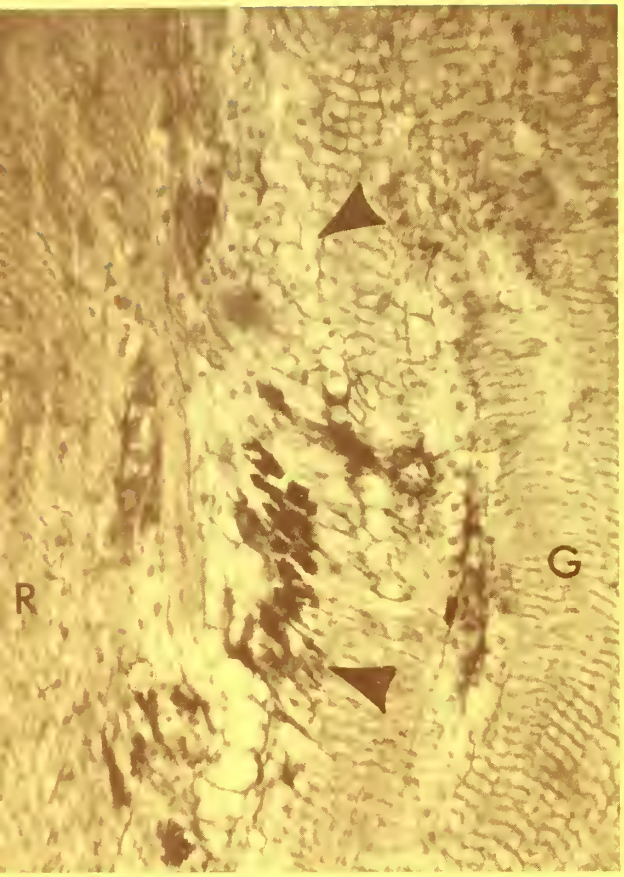

Figure 8.--An abundance of axial parenchyma was found in the xylem of union zones seen in cross section at 100X magnification. The occurrence of masses of disorganized axial parenchyma cells was fairly common in union areas of 3-year-old incompatible grafts but less frequent in 2-year-old grafts. (G, scion; R, rootstock.)

Field identification of incompatible and compatible grafts by color and length of needles and by external union appearance was accurate. Needle chlorosis and scion overgrowth were incompatibility symptoms. Only one phenotypically selected incompatible graft lacked the characteristic recessed xylem areas. Also only one phenotypically selected compatible graft was found to be incompatible. The latter was a 2-year-old graft, and it may not have had adequate time for external symptoms to become apparent. Since only 2 incorrect estimates out of 40 were made, the correlation between phenotypic selection and internal structure was good. Phenotypic roguing of incompatible grafts in the United States can be done at the end of the second or third year. Good results have been obtained in New Zealand when roguing was done at the end of the first year (see footnote 1). Accurate detection of incompatibility 1 year sooner than in Oregon may be due to the faster growth in New Zealand. With accurate external roguing, anatomical testing is not necessary.

RESEARCH SUMMARY

Microscopic study of lodgepole pine grafts showed incompatibility resulted in unequal xylem growth in union and nonunion areas. In incompatible grafts, xylem growth ceased abnormally early or grew very slowly during the summerwood

period, while contiguous nonunion xylem areas continued normal growth. Unequal growth of adjacent cells resulted in recessed union areas that completely encircled the graft union. Compatible grafts had nearly equal growth in union and nonunion areas and did not form recessed xylem areas. Phenotypic roguing of incompatible grafts is accurate when done 2 or 3 years after grafting. Useful roguing criteria are needle chlorosis and scion overgrowths. Anatomical tests for incompatibility are not necessary.

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